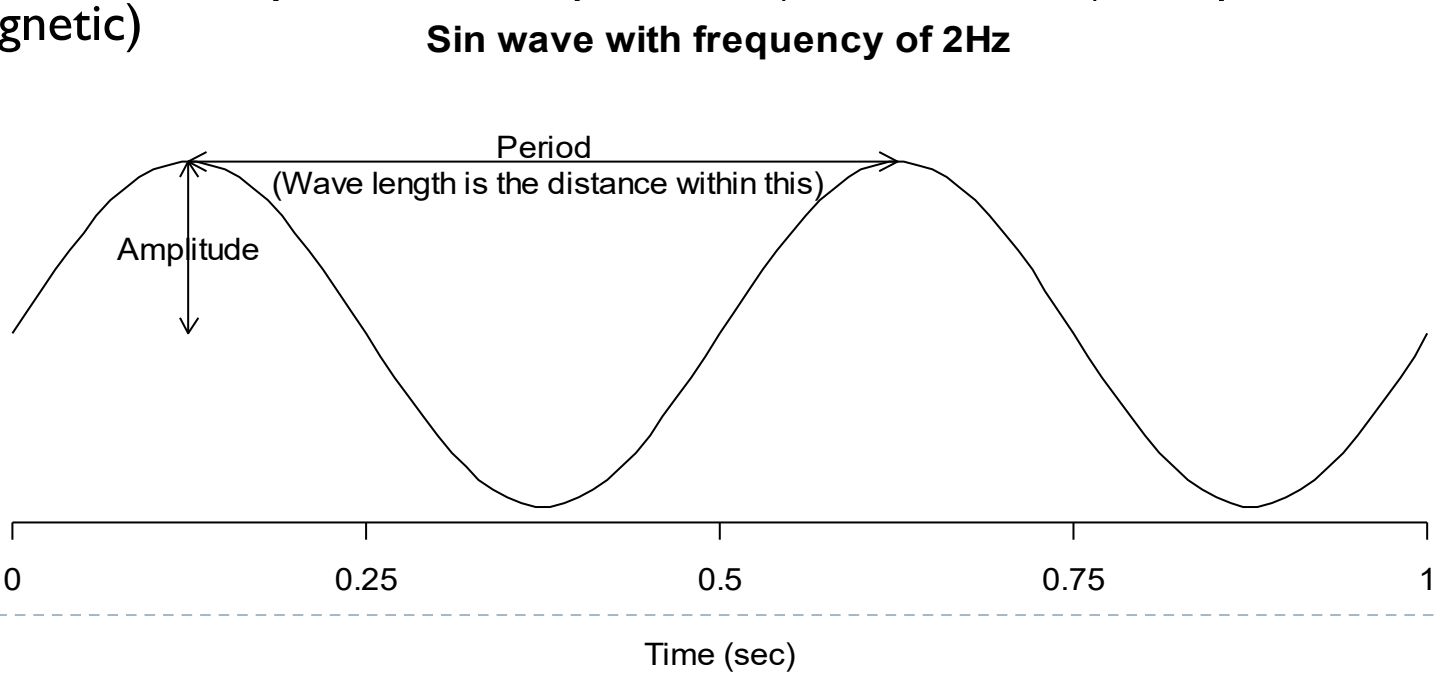
Noise, Vibration and Radiation

Upton AC: Chapter 21 "Radiation", In: Frumkin H. [Ed.] "Environmental Health: From Global to Local 2nd Ed." Jossey-Bass, 2010.
Moeller MP: Chapter 22 "Radiation", In: ibid. 3rd Ed., 2017.

23 January 2025

Basics of noise, vibration and radiation

- All of these are "waves"
- Frequency (F) and wave length (L) are critical. Both are related with velocity (V).
  - V = L x F
  - In the case of noise, sound speed (340 m/s, air, room temp.)＝L(m)×F(/s)
  - In the case of electromagnetic wave, light speed (300000km/s＝300Mm/s)＝L(m)×F(MHz)
- Differences are **media**
  - Noise is (in general) air wave (atomospheric oscillations)
  - Vibration is ground (though underground is sometimes liquid) wave
  - Radiations are caused by accelerated particles (atom/electron) and photons (electromagnetic)

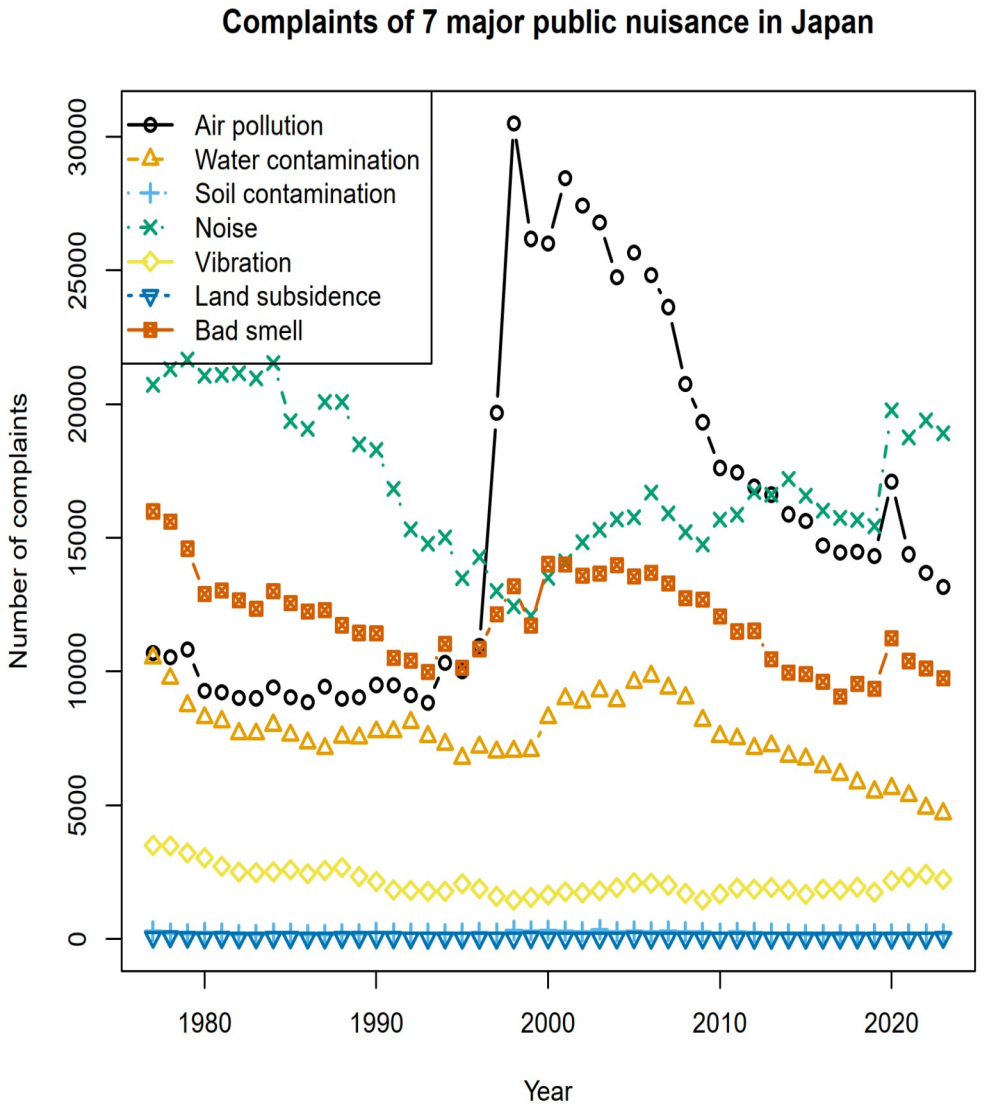


Noise

- References
  - WHO EUROPE / Noise
    https://www.euro.who.int/en/health-topics/environment-and-health/noise
  - Goelzer B, Hansen CH, Sehrndt GA: "Occupational exposure to noise: evaluation, prevention and control.", WHO
    https://www.who.int/occupational_health/publications/noise.pdf
  - Niemann E, Maschke C: "Noise Effect and Morbidity", WHO LARES Final Report, WHO EUROPE
    https://www.euro.who.int/__data/assets/pdf_file/0015/105144/WHO_Lares.pdf

Noise: disagreeable and undesirable sound or other disturbance

- Highly subjective: different by culture / individuals
  - Japanese famous *haiku* "Shizukasa ya iwa ni shimiiru semi no koe (How still it is here. Stinging into the stones. The locusts' trill)"
  - Most Western people feels noise as cricket's sound (According to Tadanobu Tsunoda, only Japanese and Polynesian recognize the insects' sound as similar to language) **https://www.youtube.com/watch?v=anIga_6qQFk**
  - Punk or heavy metal music are apparently noise for the people who hate those.
- Common source: Factory, Construction site, Car, Airplane
- In Japan, the top cause of complaints against public nuisances, as well as air pollution
  - Claims increased in 2020, probably due to the increase of stay-at-home time by COVID-19 pandemic.



What is sound?

- Air oscillation → drum → inner ear → hair cells → brain perception
- Physical strength of sound
  = sound power (W) and intensity (I)
  - $I = (p_{rms})^2/(\rho c)$ (W/m^2)
    p_{rms}=root mean square amplitude=sound pressure (N/m^2),
    ρ=density of air (1.2 kg/m^3), c=speed of sound
    * ρc= 414 $(Ns/m^2$ at 20˚C)
  - $W = 4\pi r^2 I$, r = distance from source
- Perception of sound
  =sound pressure level (Lp) / **sound intensity level (Li)**
  - Human sense is proportionate to the logarithm of the stimulus (*Weber-Fechner law*) and the sense of sound intensity is proportionate to αth power of stimulus (*Stevens' power law*: $Li = kI^{\alpha}$, $\alpha \approx 0.27$)
    - $Lp = 20 \log_{10} p_{rms} - 20 \log_{10} p_{ref} = 20 \log_{10} p_{rms} + 94$ (dB)
    - Minimum audible intensity of healthy youth I_0 ($I_0 = 10^{-12}$ W/m^2), **$Li = 10 \log_{10} (I / I_0) = 10 \log_{10} I + 120$ (dB)**
- Higher frequency sound corresponds to distant (apex side) hair cells, which makes human feel higher pitched, in the cochlea within the inner ear.

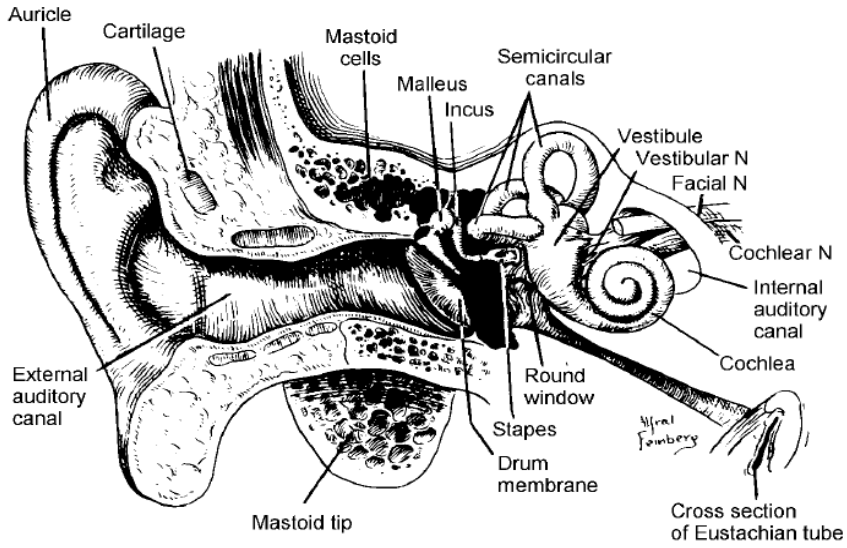


Figure 2.1. The pinna and external auditory canal form the outer ear, which is separated from the middle ear by the tympanic membrane. The middle ear houses three ossicles, the malleus, incus and stapes and is connected to the back of the nose by the Eustachian tube. Together they form the sound conducting mechanism. The inner ear consists of the cochlea which transduces vibration to a nervous impulse and the vestibular labyrinth which houses the organ of balance. (from Hallowell and Silverman, 1970)

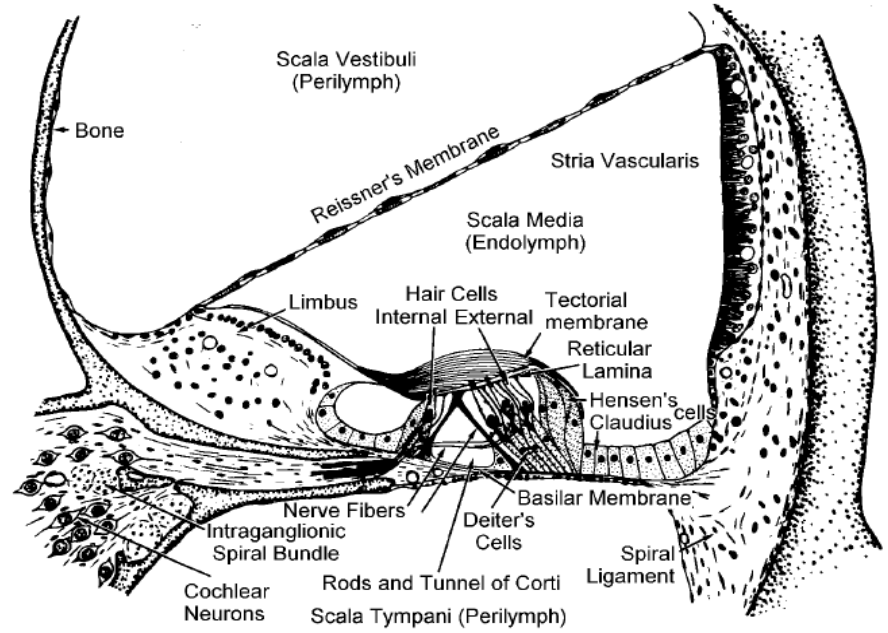


Figure 2.3. A cross section of one turn of the cochlea showing details of the membranous labyrinth. (from Hallowell and Silverman, 1970)

Source of illustrations: https://www.who.int/occupational_health/publications/noise.pdf

Noise levels

- Human perception differs by the frequency even if the same pressure/intensity levels are given. Human is more sensitive for the lower frequency than 1,000 Hz （Hz is pronounced as hertz, 1 Hz =1 cycle per second), shown as the loudness level contour.
- Noise is a complex of various sounds with a variety of frequencies, which is evaluated as weighted intensity levels as dB(A) or dB(C), usually dB(A) is used.
- Equivalent sound level (*Leq*): Automatically measured by integration sound level meter.
  - Sound intensity level (Li) shows instantaneous value, but noise levels vary with time.
  - *Leq* (equivalent continuous sound level) is the steady sound pressure level which, over a given period of time, has the same total energy as the actual fluctuating noise. For a duration of noise *T*, *Leq* is given as below (*p(t)* is sound pressue at time *t*, p_0 is the reference pressure, 20 μPa):

$$L_{eq} = 10 \log_{10} \left(\frac{1}{T} \int_0^T \left(\frac{p(t)}{p_0} \right)^2 dt \right)$$

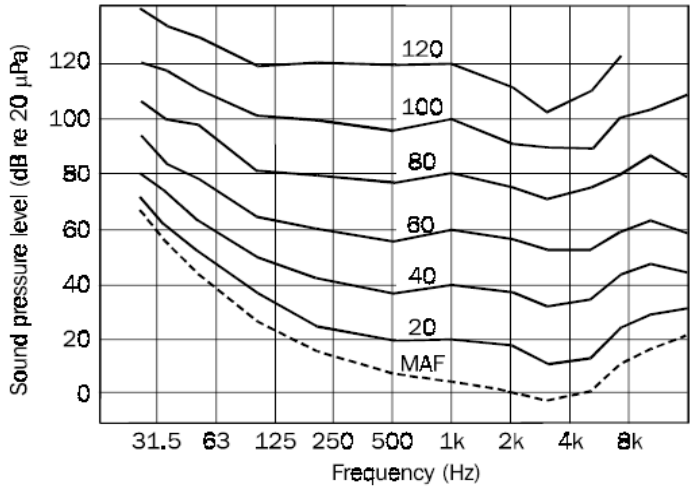


Figure 1.8. Loudness level (equal-loudness) contours, internationally standardised for pure tones heard under standard conditions (ISO 226). Equal loudness contours are determined relative to the reference level at 1000 Hz. All levels are determined in the absence of the subject, after subject level adjustment. MAF means minimum audible field.

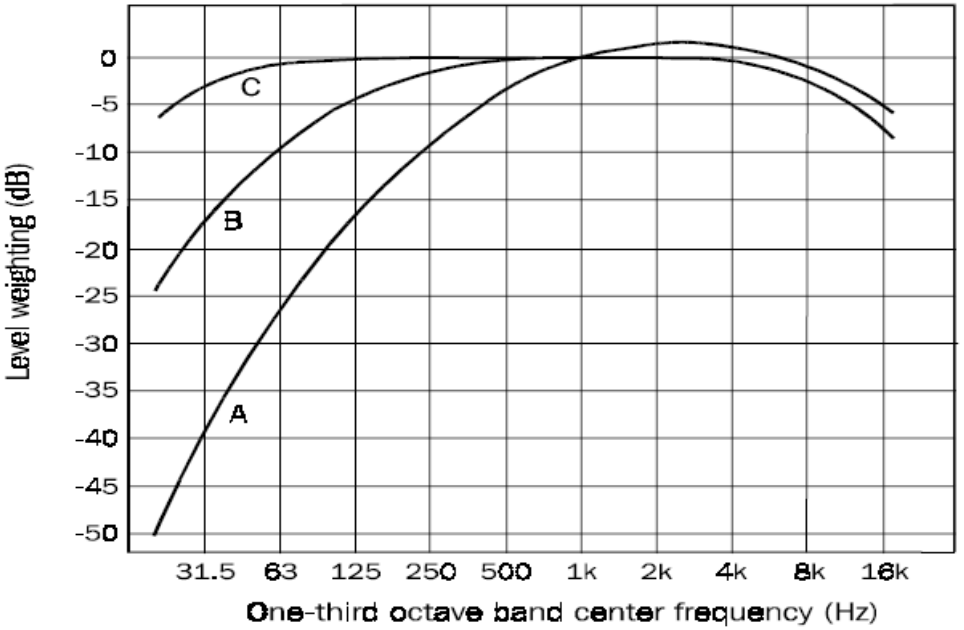


Figure 1.9. Frequency weighting characteristics for A and C networks.

Source of illustrations: https://www.who.int/occupational_health/publications/noise.pdf

Classification of sounds

- Pure sound vs noise
  - Pure sound is sine wave
  - Noise is usually a complex of the pure sounds with various frequencies
  - Pure sound with too high intensity makes human noisy
- Ultrasound
  - The sound with higher frequencies than the human audible ranges (usually considered as 20～20,000 Hz)
    - Human can feel ultrasound even if one cannot listen = hypersonic effect, possibly via bone conduction https://doi.org/10.1152/jn.2000.83.6.3548
  - Sensitivity to the sound with higher frequencies declines with ageing
    - So called "mosquito sound" is used to make youth gangs away
  - The ultrasound with MHz frequencies is used for "Echo" diagnosis, in which device the reflections at tissues are detected, so that gastrointestinal tract and lung – including air in those organs – cannot be examined by this device

Inaudible High-Frequency Sounds Affect Brain Activity: Hypersonic Effect

TSUTOMU OOHASHI,[1,2] EMI NISHINA,[3] MANABU HONDA,[4,5] YOSHIHARU YONEKURA,[4,6] YOSHITAKA FUWAMOTO,[7] NORIE KAWAI,[8,9] TADAO MAEKAWA,[10] SATOSHI NAKAMURA,[6] HIDENAO FUKUYAMA,[4] AND HIROSHI SHIBASAKI[4]

[1]Department of KANSEI Brain Science, ATR Human Information Processing Research Laboratories, Kyoto 619-0288; [2]Department of Network Science, Chiba Institute of Technology, Narashino 275-0016; [3]Human Interface Research and Development Section, National Institute of Multimedia Education, Chiba 261-0014; [4]Department of Brain Pathophysiology, Kyoto University School of Medicine, Kyoto 606-8507; [5]Laboratory of Cerebral Integration, National Institute for Physiological Sciences, Okazaki 444-8585; [6]Biomedical Imaging Research Center, Fukui Medical University, Fukui 910-1193; [7]Department of Environmental and Information Sciences, Yokkaichi University, Yokkaichi 512-8512; [8]Institute of Community Medicine, University of Tsukuba, Tsukuba 305-8577; [9]Foundation for Advancement of International Science, Tsukuba 305-0005; and [10]Art and Technology Project, ATR Media Integration & Communications Research Laboratories, Kyoto 619-0288, Japan

https://mosquitoloiteringsolutions.com/shop-mosquito/

Noises in living environment

- Noise levels in living environment
  - Near the engine of airplane, 120-130 dB(A)
  - Car's alert noise, 110 dB(A)
  - Under the bridge where train passing, 100 dB(A)
  - Ambulance siren, 100 dB(A)
  - Loudly singing alone, 90 dB(A)
  - Town's crowded street, 70 dB(A)
  - Usual talk, 60 dB(A)
  - In the library, 40 dB(A)
  - Late night in rural area, 30 dB(A)
  - The sound of clock's second hand at 1 m distance, 20 dB(A)
- Various frequencies
  - Insects' sound [https://www.youtube.com/watch?v=VpjtTI2KUcA]
    - Suzumushi (*Homoeogryllus japonicus*) 4,000-5,000 Hz
    - Kirigirisu (*Gampsocleis* spp.) 9,500 Hz
    - Kantan (*Oecanthus longicauda*) 2,000 Hz
  - Human talk is mostly around 1,000Hz, so that analog phone only transmits 300-3,400 Hz, thus suzumushi's voice is not audible via analog phone (PHS or Hikari digital phone can pass through)
  - Ambulance siren is composed of the pure sounds with 2 frequencies (960 Hz and 770 Hz)
- **Listening ability is usually tested for the frequency range of 125Hz～8,000Hz by audiometer**
  (if 0 dB is not audible, the one has hearing impairment).
- Sensorineural hearing impairment is tested about bone conduction

Health effect of noises

- Noise induced hearing impairment
  - NITTS (Noise Induced Temporary Threshold Shift)
  - NIPTS (Noise Induced Permanent Threshold Shift) = hearing impairment by noise=c^5-dip
    - Exposuse to 90dB(A) for 8 hrs everyday makes human difficult to hear the sounds with 3,000-4,000 Hz (The peak frequency of impairment is about 5,000 Hz). c^5 -dip is named by German researcher, so that the name is German style. In international (USA) way, it's C8 (The highest key of the piano).
    - Using earplugs is recommended in front of loud speaker at Live house.
- Low frequency noise
  - Many people complains the noise of outer machines of air conditioner, of which frequency is usually lower than 100 Hz.

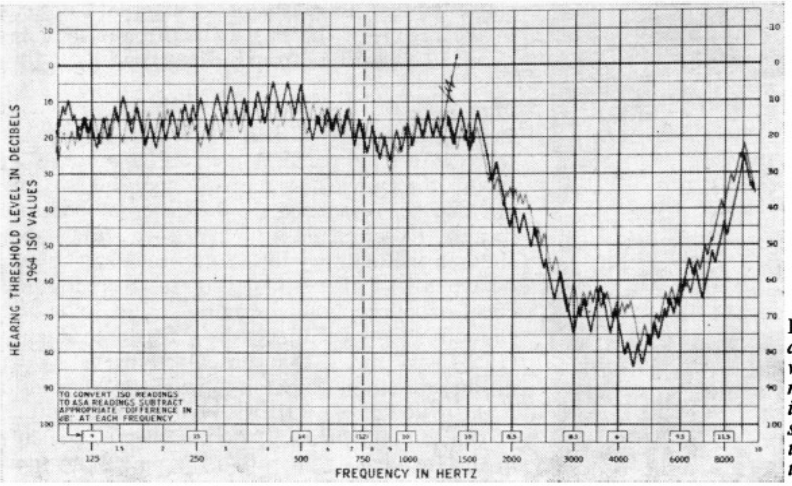


Fig 4 *Sweep frequency Békésy audiogram of right ear of man with history of occupational noise exposure, showing classical high-tone notch. Note also superimposition of sustained test tone and pulsed test tone thresholds*

Table 5.2. Number and percentages for some selected occupational diseases/disorders in 1998 (total in Germany, from BMA, 1999).

	cases registered for first time		cases recognized for first time without indemnity		cases registered & indemnified for first time (reduction of earning ability ≥ 20%)	
Occupational diseases/disorders	number	%	number	%	number	%
meniscus	2398	2.8	418	2.0	275	4.5
damage from vibrations	1797	2.1	234	1.1	154	2.5
impaired hearing	12400	14.5	7439	36.5	1012	16.4
silicosis	2813	3.3	2100	10.3	391	6.4
skin disorders	23349	27.3	1855	9.1	582	9.5

https://www.who.int/occupational_health/publications/noise.pdf

Source: Hinchcliffe R (1967) Occupational noise-induced hearing loss. Proc. Royal Soc. Med., 60: 1111-1117. [https://doi.org/10.1097/jom.0000000000001423]

Environmental regulation criteria

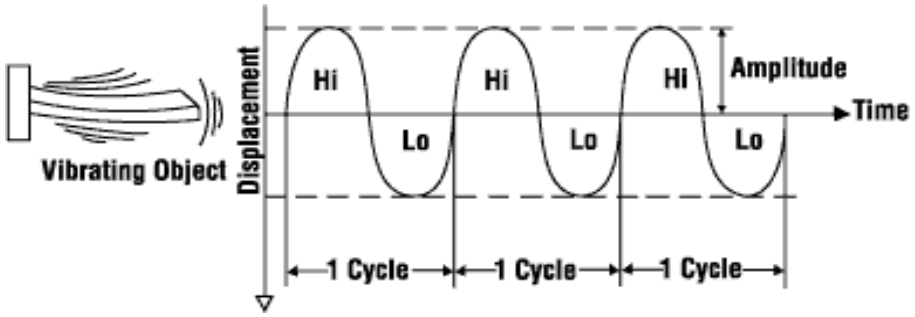
- Noise regulation act (in Japan)
  - https://www.env.go.jp/en/laws/air/noise/index.html
  - Within the area specified by the prefecture governer (densely inhabited area, close to hospital or school), the noise caused by factory, constructing action, car is regulated
  - In AA area (eg., close to many rehabilitation hospitals): less than 50 dB(A) during daytime, 40 dB(A) at night
  - In A and B area (mostly for houses): AA criteria + 5 dB
  - In C area (for commercial and factory): AA criteria + 10 dB
  - Along the road: Daytime 60 dB(A) and Night 55 dB(A) in A area, +5 dB in B and C area
  - Along the main road: Less than 70 dB(A) in daytime, 65 dB(A) at night
  - Airplane noise is specially regulated with weighted equivalent continuous perceived noise level (WECPNL).

Vibration

- References
  - ILO (1977) Protection of workers against noise and vibration in the working environment
    https://www.ilo.org/safework/info/standards-and-instruments/codes/WCMS_107878/lang--en/index.htm
  - WHO Occupational health section
    "Protecting Workers' Health Series No. 10 - Occupational exposure to vibration from hand held tools: A teaching guide on health effects, risk assessment and prevention"
    https://www.who.int/occupational_health/publications/Protecting_Workers_Health_Series_No_10/en/
  - Occupational Health and Safety Reps, Australia >> Vibration
    https://www.ohsrep.org.au/vibration_he01zvjn4l4wtpwayrxcsa

Basic Physics of Vibration

- Frequency and its intensity
  - Frequency (Hz): The number of cycles that a vibrating object completes in one second
  - Intensity (dB): vibration acceleration level, depending on Amplitude (m)
- Basic features
  - Measured by vibration meter or vibration level monitor
  - Human sensible frequencies of vibration: 0.1 – 500 Hz
- Canadian Centre for Occupational Health and Safety's https://www.ccohs.ca/oshanswers/phys_agents/vibration/vibration_intro.html



Causes of Whole Body Vibration (WBV)

- Operators, drivers and passengers of machines and vehicles in workplaces can be exposed to harmful levels of whole body vibration. The main sources of harmful WBV in vehicles and machines are: rough road and surface conditions and resistance forces, e.g. mobile plant with scraper blades / vehicle activity / engine vibration
- Factors that can increase or decrease WBV exposure include: road construction/ maintenance / vehicle type/design / vehicle age/condition / maintenance of vehicle suspension systems / seat design, suspension and maintenance / cab layout, design and orientation / task design and work organization / vehicle speed, driver skills and awareness / lighting and visibility

Causes of Hand-Arm Vibration (HAV)

- Vibration transmitted to the hand and arm during the operation of hand-held power tools and hand-guided equipment, or holding materials being processed by machines. Hand-arm vibration is commonly experienced by workers who regularly use tools such as jackhammers, chainsaws, grinders, drills, riveters and impact wrenches.
- Exposure to hand–arm vibration can be increased by factors such as: Tool characteristics (Higher magnitude of acceleration of vibration / Poor tool maintenance / Minimal handle insulation / Increased weight of tool / increased surface area of hand in contact with tool / harder material being contacted), Work organization (Long exposure during each work shift and years of exposure / lower duration and frequency of rest periods / lower temperature of work environment), Individual's characteristics (gripping the handle more tightly than needed / Awkward postures and working overhead / Low operator skill ; poor technique / individual lifestyle factors (e.g. smoking) / an individual's medical history(e.g. disease or prior injury to fingers, hands or wrists))

Health Effects and Regulation of Vibration

- Health impairment of local organ and whole body
  - Local organ (at HAV): e.g., "Raynaud's disease" causes some areas of your body — such as your fingers and toes — to feel numb and cold in response to cold temperatures or stress. Smaller arteries that supply blood to your skin narrow, limiting blood circulation to affected areas (vasospasm).
  - Whole body (at WBV): e.g. vomitting, nausea, gastrointestinal disorder, abnormal menstruation, etc.
- Environmental regulation act in Japan = Vibration regulation act
  - https://www.env.go.jp/en/laws/air/vibration/index.html
  - Regulating vibration caused by the road traffic (less than 65 dB in daytime, 60 dB at night in the area 1, +5 dB in the area 2)
  - Claimed intensity as a public nuisance are usually 60 – 80 dB
  - The vibration with 70 dB corresponds to level 2 earthquake. Level 6-7 earthquake corresponds to the vibration of 110 – 115 dB.

Effects of WBV on Low Back Pain (Meta-Analysis)

- Bovenzi M, Hulshof CT. An updated review of epidemiologic studies on the relationship between exposure to whole-body vibration and low back pain (1986-1997). Int Arch Occup Environ Health. 1999 Sep;72(6):351–65. [https://doi.org/10.1007/s004200050387]

TABLE 3

Results of the meta-analysis of cross-sectional epidemiologic studies of low back pain (LBP) *and occupations with exposure to whole-body vibration from industrial vehicles* (1986–1996). *One-year prevalence of* LBP *in the exposed and control groups, point estimates of the prevalence odds ratio* (POR) *and* 95% *confidence intervals* (CI), *adjusted at least for age, are given for each study. Random effects estimation of the summary* POR (95% CI) *and test for homogeneity between studies are reported*

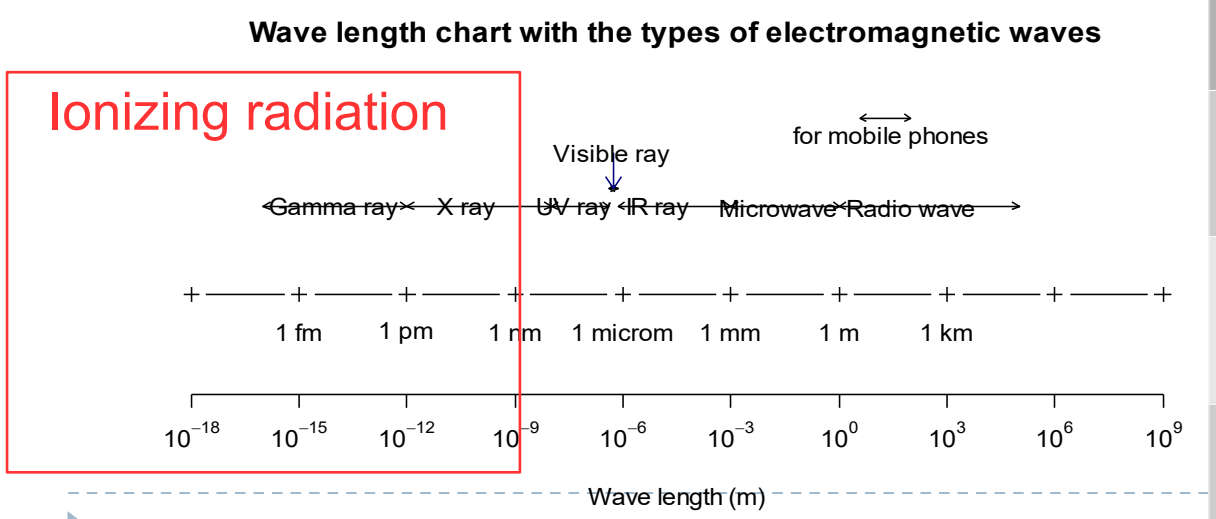
Occupational group	Ref. (no.)	Prevalence exposed group (%)	Prevalence control group (%)	POR (95% CI)	Study weight
Fork-lift truck drivers	16	65	52	1·7 (0·9–3·1)	7·3
Tractor drivers	22	31	19	2·0 (1·2–3·4)	9·2
Wheel loaders	24	47	39	1·3 (0·5–3·2)	4·0
Fork-lift truck drivers	25	57	16	7·3 (2·5–22)	2·9
Fork-lift truck drivers	25	41	29	1·6 (1·0–2·6)	10·6
Bus drivers	32	83	66	3·0 (1·8–5·1)	9·2
Crane operators	33	40	20	3·3 (1·5–7·1)	5·1
Straddle-carrier drivers	33	31	20	2·5 (1·2–5·4)	5·4
Tractors drivers	34	72	37	2·4 (1·6–3·7)	11·9
Summary POR (95% CI)				2·3 (1·8–2·9)	
Homogeneity χ^2		11·2			
Homogeneity degrees of freedom		8			
Homogeneity p value		0·19			

Radiation

- In Japanese
  - 牧野淳一郎 (2015)『被曝評価と科学的方法』岩波科学ライブラリー236
  - 中西準子 (2014)『原発事故と放射線のリスク学』日本評論社
  - 田崎晴明 (2012)『やっかいな放射線と向き合って暮らしていくための基礎知識』朝日出版社
  - 小豆川勝見 (2014)『みんなの放射線測定入門』岩波科学ライブラリー224
  - 木村真三 (2014)『「放射能汚染地図」の今』講談社
  - 小出裕章 (2011)『原発のウソ』扶桑社新書
  - 長崎・ヒバクシャ医療国際協力会（編著）(2011)『21世紀のヒバクシャ：世界のヒバクシャと放射線障害研究の最前線』長崎新聞新書
- WHO web sites
  - "Environmental radiation" [https://www.who.int/ionizing_radiation/env/en/]
  - "Ionizing radiation" [https://www.who.int/topics/radiation_ionizing/en/]
  - "Non-ionizing radiation" [https://www.who.int/topics/radiation_non_ionizing/en/]
- Other web sites
  - UN Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) [https://www.unscear.org/]
  - EURATOM [https://ec.europa.eu/programmes/horizon2020/en/print/28]
  - International Commission on Radiological Protection (ICRP) [https://www.icrp.org/]
  - International Atomic Energy Agency (IAEA) [https://www.iaea.org/]
    - https://www.iaea.org/OurWork/ST/NE/NEFW/documents/ENVIRONET/TM_ER_Radiologically_Contaminate_Sites_ANL/D1/Radiation_Overview.pdf

Radiation ray

- Accelerated particle ray + Electromagnetic wave
  - Accelerated particle ray: α ray (atomic nuclei of He), β ray (electron), Carbon ray, etc.
  - Electromagnetic wave: Photon ray, including X ray, γ ray, ultraviolet ray, visible ray, infrared ray, microwave, radio wave, etc.
- Radiation ray can be classified into ionizing and non-ionizing radiation
  - Ionizing: making electrons released when the ray goes through: X ray, γ ray, α ray, β ray, etc. The shorter wave length is, the stronger biological effects are.
  - The electromagnetic waves of which length is longer than ultraviolet are non-ionizing



Ray	Particle	Shielded by	Reachable distance in air
α	Atomic nuclei of He	A paper	Several centimeters
β	electron	Thin alminum board	About half meter
γ	photon	Thick lead board	Several hundreds meters

Basics on ionizing radiation (1)

- Radioactivity: The ability of releasing radiation ray of radionuclides: Unit is becquerel (Bq), 1 Bq is 1 disintegration per second.
- The half-life of the radionuclide is the time required for the radioactivity to decrease by decay to half of its initial value. The half-life of ^{131}I is 8 days, ^{14}C is 5,730 days, ^{134}Cs is 2.1 years, ^{137}Cs is 30.1 years, ^{90}Sr is 28.9 years, ^{239}Pu is 24,100 years, ^{235}U is 0.7 billion years, ^{238}U is 4.48 billion years: ^{239}Pu is included in the high-level radioactive wastes, which has been stored in the water pools of nuclear power stations.
- Absorbed dose: Strength of radiation damage to tissues/organs = the dose of radiation received/absorbed = Making 1 kg material to generate 1 joule (J) = 1 gray (Gy)
- Dose equivalent: The unit to measure ionizing radiation in terms of the potential for causing harm in tissues/organs = sievert (Sv)
  = Gy · Q (radiation weighting factors: α ray=20, protons and charged pions = 2, β, γ and X ray=1)

Basics on ionizing radiation (2)

- Natural radiation exposure varies by area, in average 2.4 mSv/year
- α ray mostly causes internal radiation exposure (eg. when the one take Pu-contaminated food) because it cannot reach a distant objects
- β ray from radioactive I, Cs, or Sr may also cause internal radiation exposure if the one accidentally takes those (cf. Hot spot problem)
- 3 principles of external radiation protection
  - Distance, Time, Shielding
  - Priority: Shielding > Distance > Time
- 3 principles to use radiation ray by ICRP
  - Justification: Only when total merit exceeds risk, artificial ionizing radiation can be used
  - Optimization: Exposure level has to be As Low As Reasonably Achievable = ALARA
  - Upper limit of radiation level: For occupational exposure, 100mSv/5years; for general public, 1mSv/year; not applicable for medical exposure
- Biological effects of ionizing radiation
  - Early onset effect: Mostly dose > 1 Sv, usually fatal
  - Late onset effect: According to the follow up data of Hiroshima and Nagasaki atomic bomb victims (so called "Hibakusha"), 100 mSv exposure proved to significantly increase the risk of cancer. After the Chernobyl accident, child thyroid cancer significantly increased due to internal exposure by ^{131}I.
  - The effect of lower dose than 100 mSv is still under discussion.
  - ICRP (2007) recommends to keep additional radiation exposure less than 1 mSv/year for the public. During the recovery from emergency, 1-20 mSv/year, during emergency, 20-100 mSv/year.

Average amounts of ionizing radiation received **annually** by a resident of USA

- Source: Upton 2010, ibid., p.774

Source		Dose (mSv)	% of Total
Natural			
	Radon	**1.9**	**31**
	Cosmic	**0.27**	**4**
	Terrestrial	**0.28**	**4**
	Internal	**0.39**	**7**
	Total Natural	**2.84**	**46**
Artificial			
	X-ray diagnosis	**2.4**	**39**
	Nuclear medicine	**0.8**	**13**
	Consumer products	**0.10**	**2**
	Occupational	**<0.01**	**<0.03**
	Nuclear fuel cycle	**<0.01**	**<0.03**
	Nuclear fallout	**<0.01**	**<0.03**
	Miscellaneous	**<0.03**	**<0.03**
	Total artificial	**3.35**	**54**
Total natural and artificial		**6.2**	**100**

Major 4 forms of acute radiation syndrome

Time after irradiation	Cerebral form (>50 Sv)	Gastrointestinal form (10-20 Sv)	Hemopoietic form (2-10 Sv)	Pulmonary form (>6 Sv to lungs)
Day 1	Nausea Vomiting Diarrhea Headache Disorientation Ataxia Coma Convulsions Death	Nausea Vomiting Diarrhea	Nausea Vomiting Diarrhea	Nausea Vomiting
2nd week		Nausea Vomiting Diarrhea Fever Erythema Prostration Death		
3rd to 6th weeks			Weakness Fatigue Anorexia Fever Hemorrhage Epilation Recovery (?) Death (?)	
2nd to 8th months				Cough Dyspnea Fever Chest pain Respiratory failure

- Source: Upton 2010, ibid.(pp.780, 784)

Lifetime risk of 100 mSv whole-body exposure

Estimated lifetime risks of fatal cancer attributable to 100 mSv, whole-body irradiation

	Excess cancer deaths per 100,000	
Type or site of cancer	No.	(% excess above baseline)
Colon	61	3
Lung	200	7
Bone marrow (leukemia)	65	13
Stomach	22	4
Breast	40	2
Urinary bladder	25	4
Esophagus	20	6
Liver	16	9
Gonads	24	5
Thyroid	8	8
Bone	5	5
Skin	2	2
(Remainder)	87	2
Total	575	2

- Source: Upton 2010, ibid.(pp.780, 784)

Risk assessment of radiation exposure by Nakanishi (2014)

(Yasutaka T, Naito W, Nakanishi J (2013) Cost and effectiveness of decontamination strategies in radiation contaminated areas in Fukushima in regard to external radiation dose. PloS ONE, 8(9): e75308. https://doi.org/10.1371/journal.pone.0075308)

- Exposure to toxic chemical substances: different [exposure→absorption] pathways (oral, inhalation, skin) → different target organs
- Two kinds of exposure to radiation should be distinguished:
  - Internal exposure: via oral or inhalation, radioactive materials attach and generate radiation rays
  - External exposure: via skin-attached radioactive materials or gamma ray from distant radioactive materials

Risk assessment of radiation exposure by Nakanishi (2014)

(Yasutaka T, Naito W, Nakanishi J (2013) Cost and effectiveness of decontamination strategies in radiation contaminated areas in Fukushima in regard to external radiation dose. PloS ONE, 8(9): e75308. https://doi.org/10.1371/journal.pone.0075308)

- External exposure: effective dose = (air dose)×(conversion coefficients by age)×(shielding factor) = (air dose rate)×(time spent there)×1 (in Japan; UNSCEAR suggests 0.7-0.8 for adults)× 0.6
  - (eg.) At the Katsurao village office, Fukushima in the evening on 15 Sep. 2013, air dose rate was 0.257μSv/h. If a person lives there for a year, cumulative external exposure becomes 0.257・24・365・0.6=1351 μSv (≈1.4 mSv/year)
  - In Chernobyl, shielding (behavioral) factors were 0.36 in rural, 0.18 in urban area (UNSCEAR, 2008)
- Internal exposure: Using dose conversion factor (DCF; Sv/Bq), Internal exposure dose = effective dose = (intake / Bq)×DCF = (intake/Bq/day)×(days)×DCF
  - (eg.) If a person orally ingests 170 g/day rice (375 g/day as cooked rice) with the radioactive Cs of 100 Bq/kg (maximum tolerable level) everyday, assuming that Cs is composed of half ^{134}Cs, half ^{137}Cs, of which DCFs are 1.9×10^{-8} and 1.3×10^{-8} Sv/Bq, respectively (thus 1.6×10^{-8} in average), $100・0.17・365・1.6・10^{-8} = 0.1$ mSv/year

Comic "Oishinbo" nose bleeding problem (*1)

- Based on the experience during the writer's activity at Fukushima to collect information, the protagonist of the comic Mr. Yamaoka suffered from sudden nose bleeding just after their activities at Fukushima in the story.
- The wide-range of protests occurred
  - The Fukushima prefectural government issued a protest against the comic for inflaming fears about the safety of the prefecture's fish.
  - The episodes of nose bleeding may be only highlighted by diagnostic suspicion bias.
  - Many professionals (including medical doctors) judged the story is a kind of denial of the fact, because the nose bleeding cannot be caused by the radiation emitted from Fukushima nuclear power plant (Nose bleeding is usually included in whole body acute radiation syndrome, caused by several Sv exposure).
- There were some supportive opinions, too.
  - The nose bleeding observed among the people in Fukushima and surrounding area could be caused by radiation.
  - If psychological effects contribute to the nose bleeding, it's still the effect of the accident.

***1 https://apjjf.org/2014/11/25/Eiichiro-Ochiai/4138/article.html**

Comic "Oishinbo" nose bleeding problem (*2)

- The comic clearly stated that the radiation exposure dose was much lower than the critical level to cause acute whole body syndrome.
- Mr. Kariya, the writer of the comic published the book to answer this issue. In that book, he suggest "hot" particles attached to the inner-nose skin to harm the local (inner-nose) capillary vessels, then to cause nose bleeding. Makino (2015) also suggests this possibility.
- The writer actually met many people who suffered from strange nose bleeding after the accident, so that, besides the cause, epidemiologists and/or public health specialists should assess the incidence or prevalence of the nose bleeding episode. According to the data by Nakachi and Tsuda (2013), nose bleeding incidence was significantly higher (by 3-4 times) in towns close to Fukushima daiichi nuclear power plant (*2).

Item	Kinomoto Shiga	Futaba Fukushima	Marumori Miyagi
Pop.	7056	6730	733
Res.	3775	3872	637
(%)	(56.1)	(54.9)	(86.9)
Fever	50	58	5
(%)	(1.3)	(1.5)	(0.8)
Cough+	386	521	59
(%)	(10.3)	(13.7)	(9.5)
Gum*	142	212	17
(%)	(3.8)	(5.6)	(2.7)
Nose*	14	43	5
(%)	(0.4)	(1.1)	(0.8)

Odds Ratios of Nose bleeding
(adjusted for sex, age, smoking, etc. using multiple logistic regression model) were:
3.8 [1.8-8.1] for Futaba
3.5 [1.2-10.5] for Marumori
to Kinomoto as reference
Prevalences (%) of fever, cough, gum were higher than national statistics (Kokumin-seikatsu kiso chosa).

*2 **http://www.saflan.jp/wp-content/uploads/47617c7eef782d8bf8b74f48f6c53acb.pdf**
https://iwj.co.jp/wj/open/archives/237962

Non-ionizing radiation (1): UV ray

- UV=ultraviolet ray
  - Wave length ranges from 10 to 400 nm.
  - UV-A: 320-400, UV-B: 280-320, UV-C: 190-280 nm
  - 10-190 nm UV cannot reach the earth surface.
    - UV of shorter wave length than 290 nm has strongly harm organism, but mostly absorbed in ozone layer.
    - Absorbed in skin or mucosa, harms skin and/or eyes
    - **UV-C : cytotoxic, 250-280 nm has strong effect, used for sterilization**
      - Recently UV-C of 222 nm is found to be effective for safe sterilization [https://dx.doi.org/10.1038%2Fs41598-020-67211-2]
    - **UV-B** : weak cytotoxicity, 290-320 nm can activate vitamin D in skin.
    - **UV-A** : related with tanning, cataract, and oxidant generation
  - Snow enhances reflected exposure (75% of UV is reflected by snow)
  - T-dimer of DNA generation increases the risk of skin cancer.

Non-ionizing radiation (2): visible and infrared

- Visible ray
  - Wave length: 400-700 nm. From short to long wave length: violet, blue, green, yellow, red
  - Illuminance (lx) = luminous flux (lm) / area (m^2) = brightness (cd) / squared distance (m)
  - For safe walk, 20 lx; for working, 100 lx are needed.
- Infrared ray (IR)
  - Wave length: 700 nm – 1 mm. **Heat ray**: Absorbed by materials to make them heated.
  - Near IR (700 nm – 2.5 μm, remote controller), Mid IR (2.5 μm – 4 μm), Far IR (4 μm – 1 mm)
  - Reach the subcutaneous tissues, 1 – 1.4 mm beneath the skin. If eyes absorb IR, cataract may occur.

Non-ionizing radiation (3): microwave

- Microwave
  - Wave length = 1 mm - 1 m, Frequency = 300 GHz – 300MHz
  - Widely used in microwave oven.
  - According to the Ministry of Public Management in Japan, 1 – 10 mm is mm-wave, 10 – 100 mm is microwave, 100 mm – 1 m is extremely ultra-short wave or ultra-high-frequency wave (UHF: for digital TV and microwave oven [2.45 GHz])
- Newer usage of microwave: Microwave mammography
  - In the screening of breast cancer, X-ray mammography is widely used. But sensitivity and specificity of X-ray mammography was not enough, especially the females with dense-breast. Instead of X-ray, if microwave can be used, non-ionizing microwave is quite safe. But reconstruction of mammogram from the reflections of microwave was quite difficult, because solving the reverse-scattering problem was necessary. Prof. Kimura in Kobe Univ. solved it and developed microwave mammography.
    https://www.kobe-u.ac.jp/en/news/article/2019_06_17_01/

Non-ionizing radiation (4): radiowave

- Radiowave
  - Wave length = 1 m -
  - Frequency = - 300 MHz
    - Frequencies of several MHz – 80 MHz radiowave is used in MRI. Biological influence is only seen at high energy. Regulated by SAR (specific absorption rate; W/kg). The places where SAR exceeds the criteria is restricted to enter.
    - The safety criteria of local exposure by mobile phone / PHS (800 MHz, 1.5 GHz, 1.9 GHz, 2 GHz): SAR < 2 W/kg
      - Local exposure SAR is measured as energy absorption of 10 g cube at temporal region of head of phantom.
    - Behavioral change of monkey exposed to 1 GHz radiowave occurred at 4 W/kg exposure for 1 hour, so that tolerable whole body SAR for human is 0.4 W/kg (6 minutes) in USA.

Effect and regulation for the GHz band radio waves
https://www.soumu.go.jp/main_content/000328161.pdf

- SAR (specific absorption rate, W/kg) is important to assess the risk
- The radio wave's power for mobile phones is regulated by SAR levels.
- Regulation in Japan
  - The level to affect human body = 138 W/kg for 10 g
  - The regulation criteria by Ministry statement = 2 W/kg for 10g
  - The maximum SAR levels of commercially available mobile phones = 0.183 W/kg – 1.60 W/kg (Average 0.693 W/kg)
    - PHS phones showed very low SAR (eg. 0.045 W/kg for WX01K, Kyocera)