ILC Guideline Series 6

Safety Control of the ILC

Central control center of CERN (European Organization for Nuclear Research)

Tohoku ILC Project Development Center

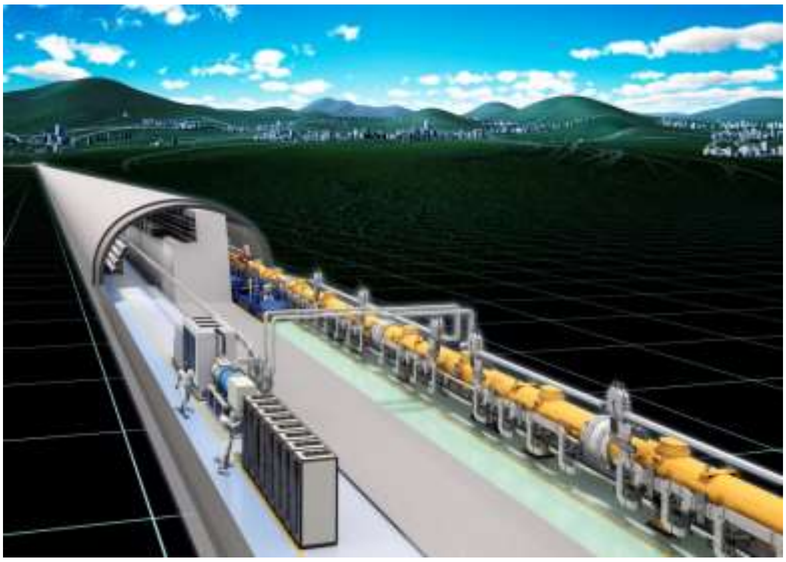
～ Contents ～

Introduction

ILC is the abbreviation for “International Linear Collider,” a facility constructed in an underground tunnel with an overall length of 20-50 km. In this facility, electrons and positrons are accelerated close to the speed of light from both ends of the facility to make them collide. In this way, the ILC is intended to clarify the origins of matter and time/space, and mysteries related to the birth of the universe.

The Kitakami Site, which is in the Kitakami Mountains extending across Iwate and Miyagi Prefectures, has been selected by researchers around the world as a candidate area for ILC construction; thus, the ILC facility and equipment specialized for the Kitakami Site are currently being designed and examined. In addition, the ILC facility will be constructed and operated with strict safety control by applying technology and experience, along with the latest knowledge, from large accelerator research facilities operating worldwide.

This guideline describes the examination conditions and other relevant information from researchers in order to deepen local residents’ and relevant persons’ understanding of safety control, a part of the ILC project. Moreover, to clearly answer questions from various people, this guideline applies the style of “frequently asked questions and answers (Q&A).”



©Rey. Hori/KEK

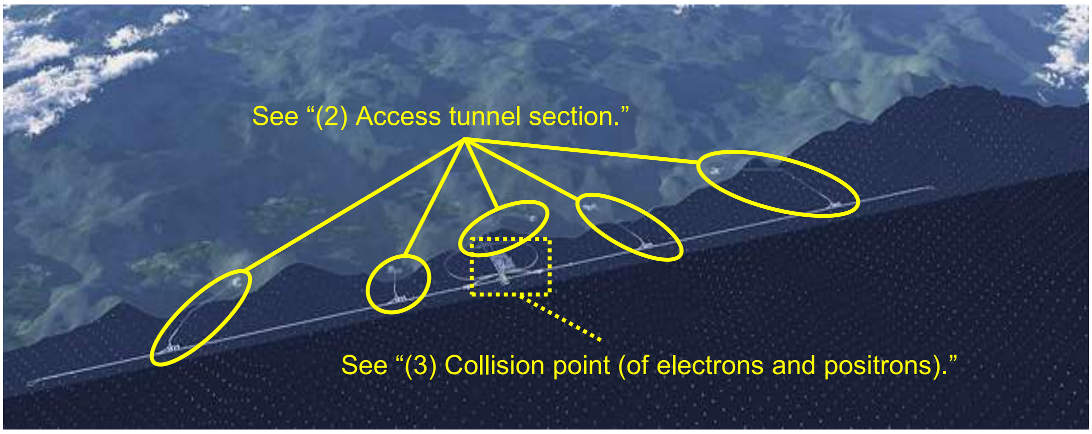
Image of the ILC constructed in an underground tunnel

Location of the Kitakami Site (a candidate area for ILC construction)

I-1 Outline of the ILC facility

(1) Connections between the underground tunnel and aboveground facilities in the ILC

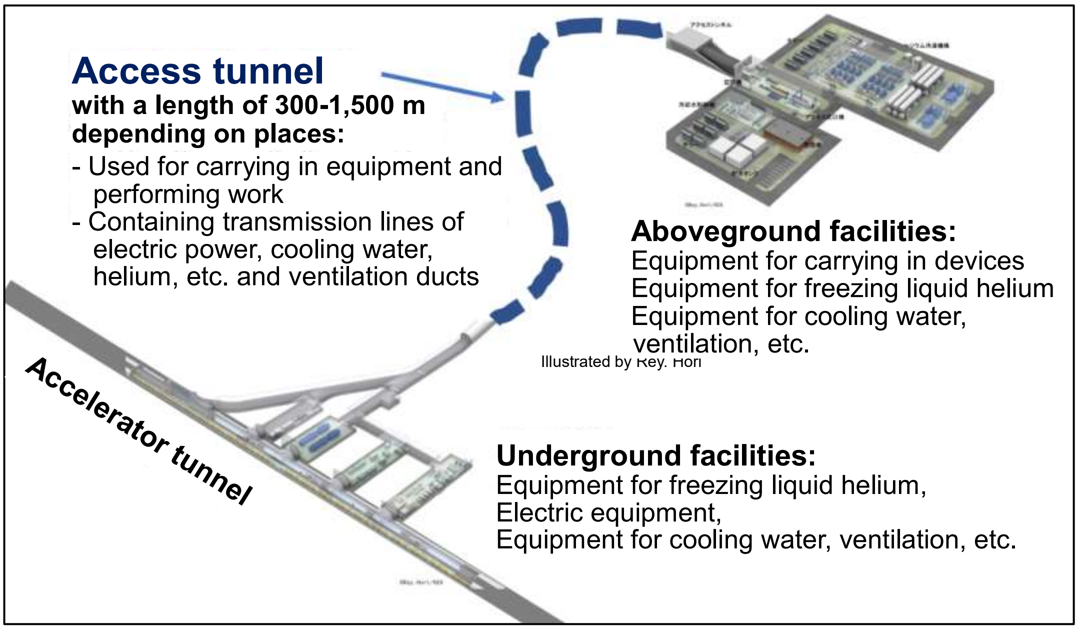
- ○ The ILC is assumed to be constructed in a horizontal underground tunnel with an altitude of approximately 110 m in the Kitakami Mountains (an area extending from Oshu City through Ichinoseki City in Iwate Prefecture to Kesennuma City in Miyagi Prefecture, where it has an overall length of 50 km).
- ○ The layer of overburden (depth from the ground surface to the tunnel) varies according to the rise and fall of mountains.
- ○ The ILC underground tunnel is connected to the surface with access tunnels and shafts.



Cross section (image) of the ILC underground tunnel

(2) Access tunnel section

- ○ Access tunnels are used for carrying in equipment and performing work from the aboveground to underground areas.
- ○ For an ILC tunnel with an overall length of approximately 20 km, access tunnels are assumed to be provided at a total of five places.
- ○ Access tunnels are assumed to have lengths of approximately 300-1,500 m, depending on their placement.



Outline (image) of an access tunnel

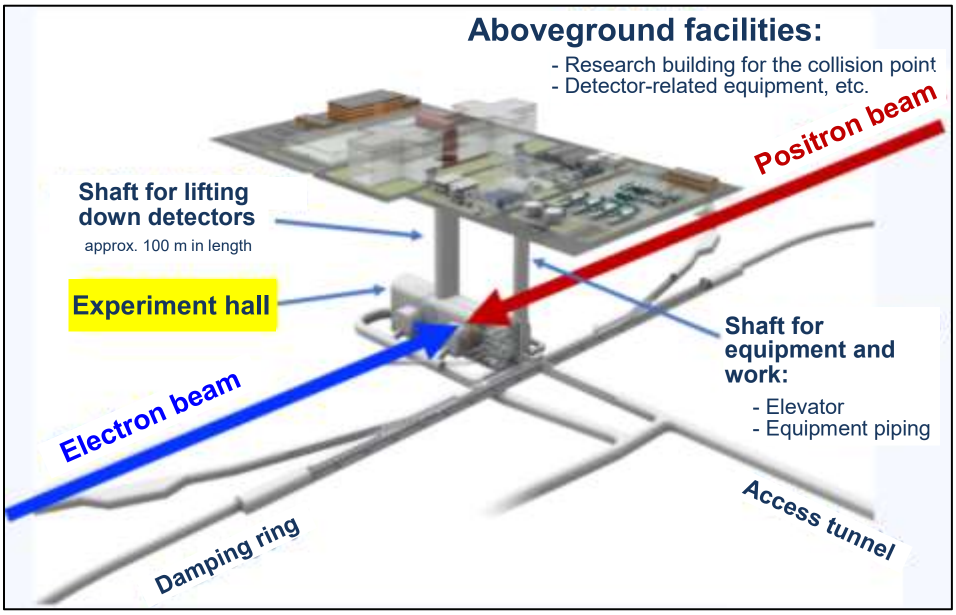
(3) Collision point (of electrons and positrons)

○ In the ILC, electron and positron beams (each of them is made up of a mass of several tens of billion electrons or positrons) are accelerated through the main linac and collide at the center of the tunnel.

○ Two large elementary particle detectors will be installed at this collision point to observe the reaction of electrons and positrons in detail.

○ The whole of the aboveground facilities will have a size of several hectares and contain a collision point research building, detector-related equipment, and other relevant devices.

○ Shafts for lifting down the large detectors and for equipment and work will be provided from the aboveground facilities to the experiment hall.



Outline (image) of the collision point and its vicinity ©Rey. Hori/KEK

(4) Safety devices for the accelerator

○ In the ILC, safety devices will be integrated for some functions such as observing the operating conditions of equipment continuously and stopping the operation of beams automatically in case of any abnormalities. The safety devices will actually perform the following functions:

◆ Monitoring the soundness of the accelerator (including electromagnets, high frequency devices, and beam dumps)

- Monitoring conditions (including temperature, current, voltage, the degree of vacuum, and the amount of cooling water)
- Checking operational setting values (measures against wrong operation, including integrated circuits and calculators)

◆ Monitoring beams

- Including beam intensity, beam paths, and energy

◆ Monitoring radiation doses

- Installing radiation monitors in various locations

◆ Controlling access

- Including entrance/exit area control, emergency stop switches, and door sensors

I-2 Q&A: Safety control

Q1. Is it safe in case of a megathrust earthquake?

A1. Since the maximum acceleration, an indicator for the intensity of an earthquake, for under the ground is proven to be attenuated to 1/2 to 1/4 of that for above the ground, a megathrust earthquake is considered to have little effect on underground devices.

The ILC facility will be designed to be safe (no major failures occur in its functions) even if an earthquake equivalent to a seismic intensity of 7 occurs.

In case of an earthquake, beams will be stopped immediately upon the detection of shaking.

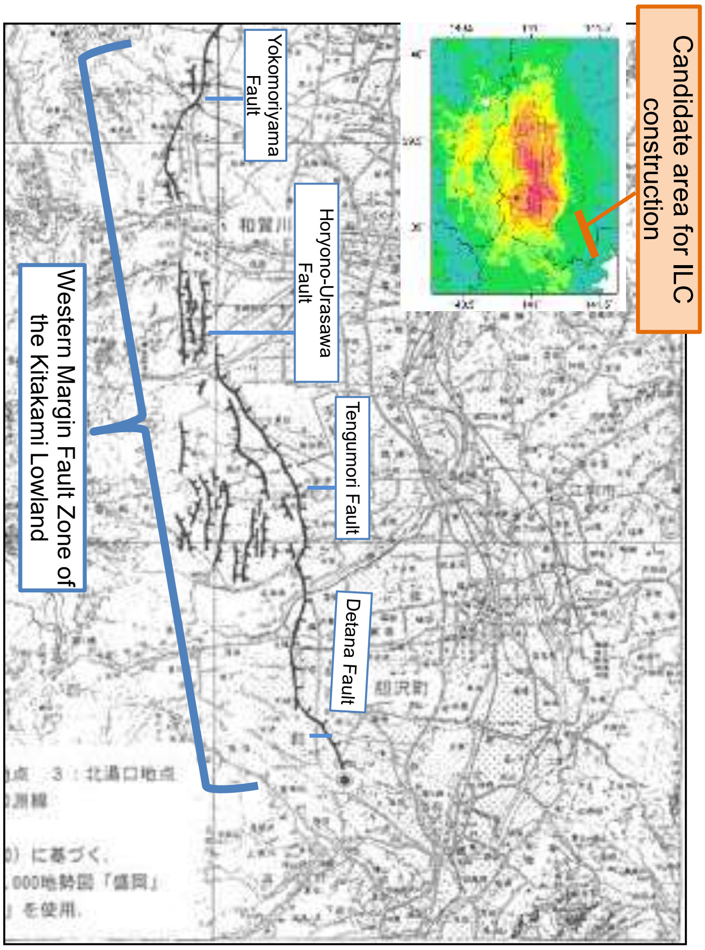
- In the 2011 Tohoku Earthquake, observation results of seismometers on the ground surface and at a depth of approximately 100 m under the ground show that maximum underground acceleration was 0.242 times that of the surface in Fujisawa (of Iwate Prefecture) with a seismic intensity of 6-Lower and 0.225 times in Towa (of Iwate Prefecture) with a seismic intensity of 5-Upper.
- The Esashi Earth Tides Station of the National Astronomical Observatory (established in a tunnel with a length of 250 m and a depth (overburden) of 40-60 m halfway up Mt. Abara) has quartz-tube strain meters made of quartz glass, which were not damaged at all even in the 2011 Tohoku Earthquake.
- KEK (the High Energy Accelerator Research Organization) in the City of Tsukuba experienced shaking with a seismic intensity of 6-Lower in the 2011 Tohoku Earthquake, but its electron/positron collision circular accelerator installed at 10 m under the ground were stopped safely and its devices only had a little lateral shift; thus, the accelerator was restored and operation resumed 10 months later.

Esashi Earth Tides Station
(provided by the National Astronomical Observatory)

Q2. Is the ILC impacted by the Western Margin Fault Zone of the Kitakami Lowland?

A2. Since the Western Margin Fault Zone of the Kitakami Lowland is at least 20 km distant from the candidate area for ILC construction, it is considered to have no impact on the ILC.

- The Western Margin Fault Zone of the Kitakami Lowland (with a length of approximately 62 km) is located near the border between the Ou Mountains and Kitakami Lowland to the east.
- If this fault zone activates, **a seismic intensity of approximately 4 to 5-Lower on the surface near the candidate area for ILC construction is expected** (from the Headquarters for Earthquake Research Promotion).



Places of the Western Margin Fault Zone of the Kitakami Lowland and the candidate area for ILC construction
(Edited materials from the Headquarters for Earthquake Research Promotion)

Q3. Is it safe in case of a power outage?

A3. When a power outage occurs, the accelerator will stop because it runs on electricity. Control of the accelerator will not be lost, unlike in nuclear reactor accidents.

If a power outage continues for a certain period or more, independent power generators will start and aboveground devices will take safety measures such as collecting cooling helium.

Q4. Does electricity usage impact the vicinity?

A4. The ILC is estimated to require a total electric power of 120,000 kilowatts in the original plan (for a length of approximately 20 km). This power is approximately 0.5% of the power station capacity of Tohoku Electric Power (approximately 1% of the generated and received electric energy) (*), so power supply and demand in the vicinity will not be impacted on by this.

Moreover, in summer and winter when power supply and demand are high, a shutdown period of the ILC will be set, and servicing and maintenance will be carried out for its devices and equipment to lower power usage.

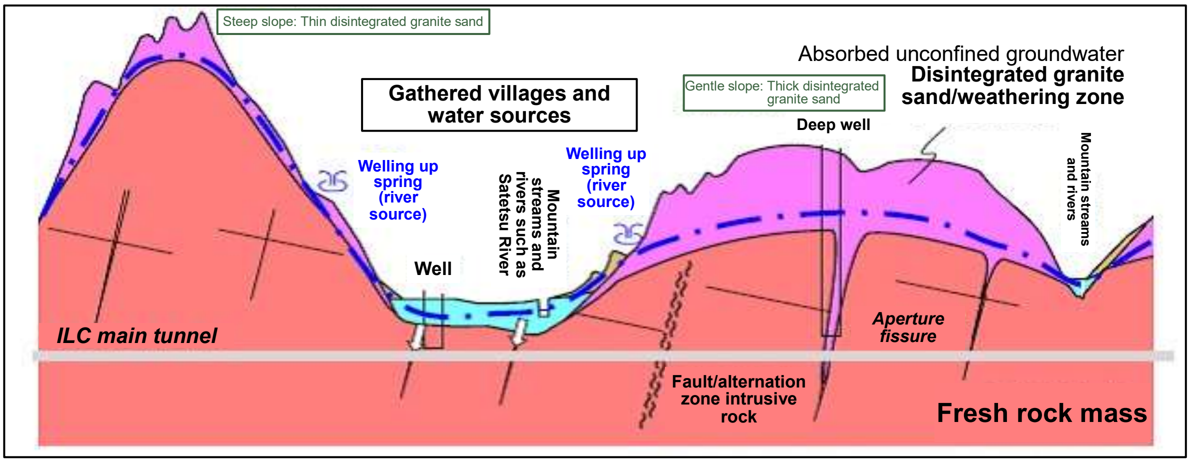
* A power station's capacity is the electric power that can be supplied when all equipment is operating.
The generated and received electric energy is the total of the electric energy generated by the company itself and that received from other companies. It corresponds to the annual actual supply power. Note that Tohoku Electric Power now generates electric power by means of water power, thermal power, and new energy (wind power, photovoltaic, and geothermal power) stations and does not use nuclear power stations (which are suspended).

Q5. Is it safe for groundwater?

A5. Hydrologic surveys were conducted in the candidate area for ILC construction. From the results of these surveys, water systems near the area have been understood and the distribution of groundwater is estimated. Sufficient measures for the future will be taken through detailed surveys.

- ■ Outline of conducted hydrologic surveys: The surveys were conducted for the purpose of understanding water system conditions in the candidate area for ILC construction and the impact of ILC tunnel construction on the surface and underground areas. (The surveys consist of estimating the surface of groundwater by river flow and topographical analyses and estimating the amount of water welling up by providing pits for groundwater observation (for the water level and temperature in a pit).)
- ■ Results of conducted hydrologic surveys: In areas of high overburden, water usage is only affected a little. In low overburden areas, water usage may be affected.

⇒ Impacts will be expected and evaluated, and measures will be established through preliminary surveys.



Hydrologic and geologic structure assumed in a granitic area

I-3 Q&A: Consideration of environment

Q1. How will sediment from the excavation be disposed of?

A1. Excavated muck will be stored in a temporary space. Then, a part of it is to be reused in the ILC facility, public works, and other places as concrete aggregate or bank materials, and the rest of it will be used for reclamation in muck disposal plants.

These places will be examined in terms of disaster prevention, transportation costs, the impact of carrying in/out muck on local residents, landscapes, and other relevant matters.

- The total amount of excavated muck from the construction of an ILC tunnel with an overall length of approximately 20 km and five access tunnels is assumed to be approximately 3.5 million m^3 (the handling amount of carrying out muck is approximately 5.6 million m^3).
- If sediment and muck are found to contain too much naturally occurring heavy metal, measures necessary to prevent any impact on the environment will be taken according to relevant laws and regulations.

Q2. Does it impact animals and plants?

A2. Environmental assessment surveys will be conducted sufficiently in the construction preparation phase to minimize any impact. In addition, if any major impact is found, sufficient measures will be taken.

Note that so far, natural environment surveys have been conducted around the planned route of the ILC tunnel, and the draft of the environment impact assessment methods has been established.

Q3. Does it impact the landscape?

A3. In the ILC, the campus and facilities are intended to coexist with the natural woodland, and will be designed by incorporating the opinions of local residents.

- Major ILC facilities are underground, while the laboratory, aboveground pitheads for accessing tunnels, and surrounding experiment preparation facilities are above the ground.
- For aboveground facilities, the shapes of pitheads will be designed and safety measures, waterproofing measures, evacuation guidance equipment, and the maintenance of disaster prevention information systems will be examined so as to avoid affecting the landscape or inducing disasters such as landslides due to construction.
- Activity cases of CERN (European Organization for Nuclear Research):
  - To reduce noise and hide the structures of experimental facilities, trees are planted and buildings and cooling towers are designed to be as low as possible.
  - Saplings that have been grown for five years are transplanted in access areas to harmonize with buildings and the landscape on the ground surface.

[Conditions of CERN]

II Radioactivation of matter by an accelerator

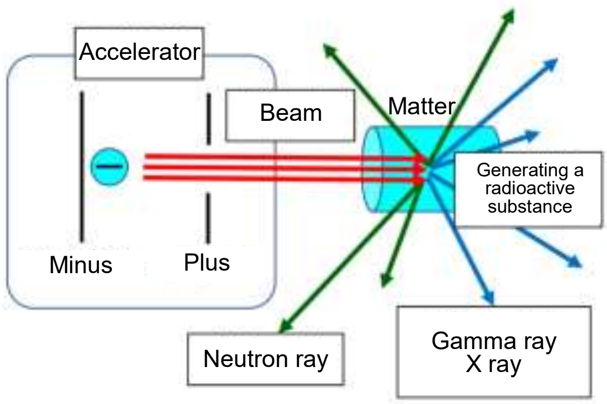
Radioactivation occurs in a limited place where beams collide. When radioactivation occurs in a device, radioactivated matter (a radioactive substance) remains in the material.

(1) Radioactivation by an accelerator

A beam smashes matter → Radiation (*) and a radioactive substance are generated.

Radioactivation: A phenomenon of matter, which had no radioactivity, becoming radioactive

Degree of radioactivation:
- **Amount** of beam
- **Type** of beam **particles**
- **Energy** of beam
- **Type of matter**

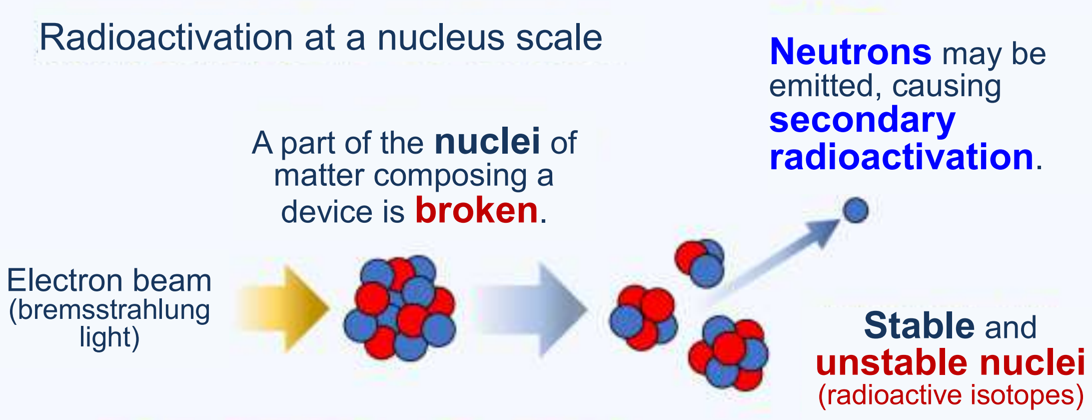


(Case where an accelerated beam smashes matter)

- **Radioactivated matter (a radioactive substance) emits radiation.**

* Radiation: Material particles flowing with high kinetic energy, or a general term for alpha rays (helium nuclei), beta rays (electrons), neutron rays, proton beams, heavy particle beams, gamma rays of high energy electromagnetic waves (light), and X rays

(2) Mechanism of radioactivation

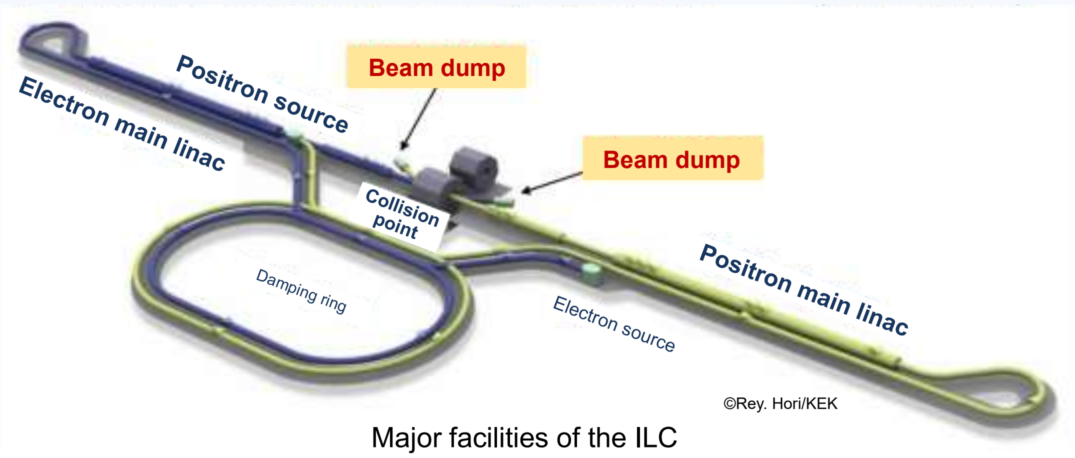


- **Generated nuclei are lighter than broken nuclei.**
- **Radioactivation** may occur **by incorporating neutrons.**
- Radioactivation of an accelerator (including iron, copper, and concrete) **cannot generate cesium and iodine** that have heavier nuclei.

III-1 Safety control of radiation in the ILC

(1) Devices composing the ILC and radiation/radioactivity to be generated

	Beam power loss
(i) **Beam dump: Radioactivation by absorbing beams**	**(2 x 2,600 kW)**
(ii) Positron source: Radioactivation of a target	(12 kW)
(iii) Main linac: Radiation when accelerating a beam	(2 x 1 kW)
(iv) Collision point: Particles dispersing due to collision	(0.1 kW or less)



Major facilities of the ILC

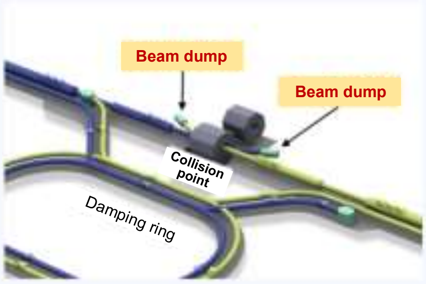
(2) Beam dump

A beam dump contains water where tritium is accumulated.

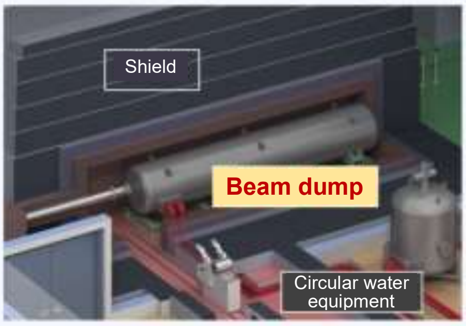
- **Stops a beam safely.**
  Radioactive substances are generated most frequently.

- **Absorbs a beam in water.**
  If beams are operated continuously for 20 years, **for the total of two beam dumps**:
  (i) **approximately 100 tons of water**,
  (ii) tritium with a maximum radioactivity of 100 trillion Bq is evaluated to be accumulated.

- This water will be operated as enclosed **circulation water in controlled equipment rooms**.
- **This water will not be drained** even during maintenance or other service tasks.



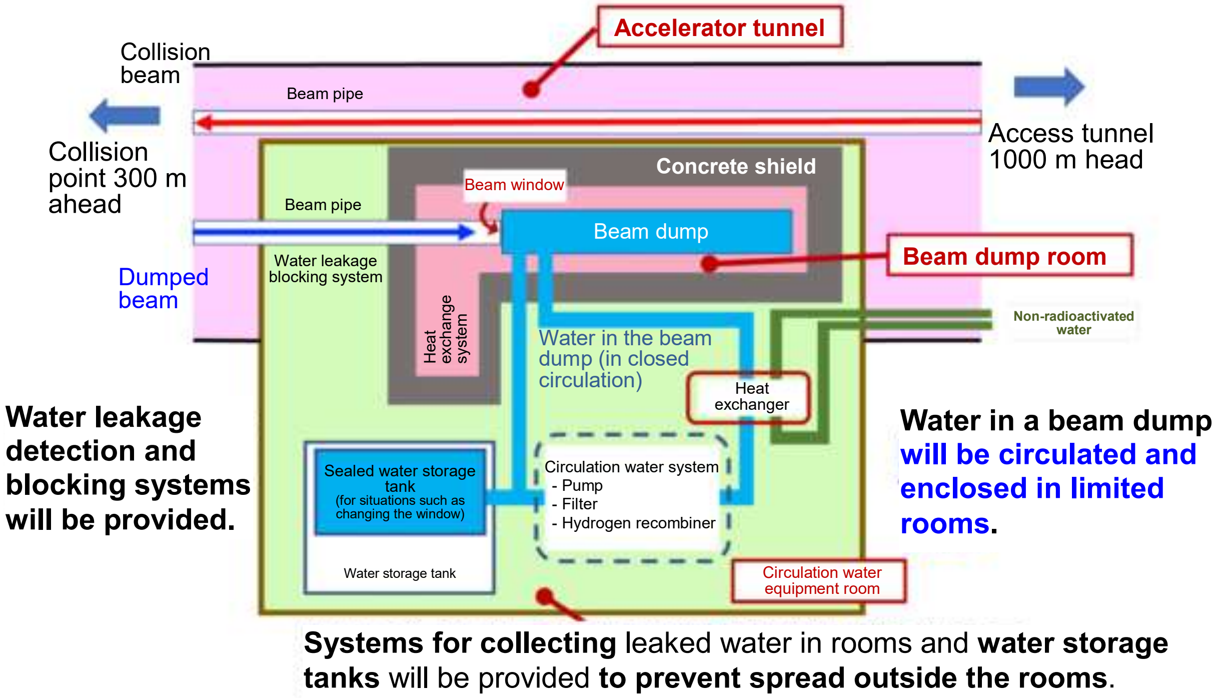
©Rey. Hori/KEK



©Rey. Hori/KEK

(3) Control of water in a beam dump and spread prevention measures

Water in a beam dump will not be drained. (It is used in circulation.)



Circulation of water in a beam dump

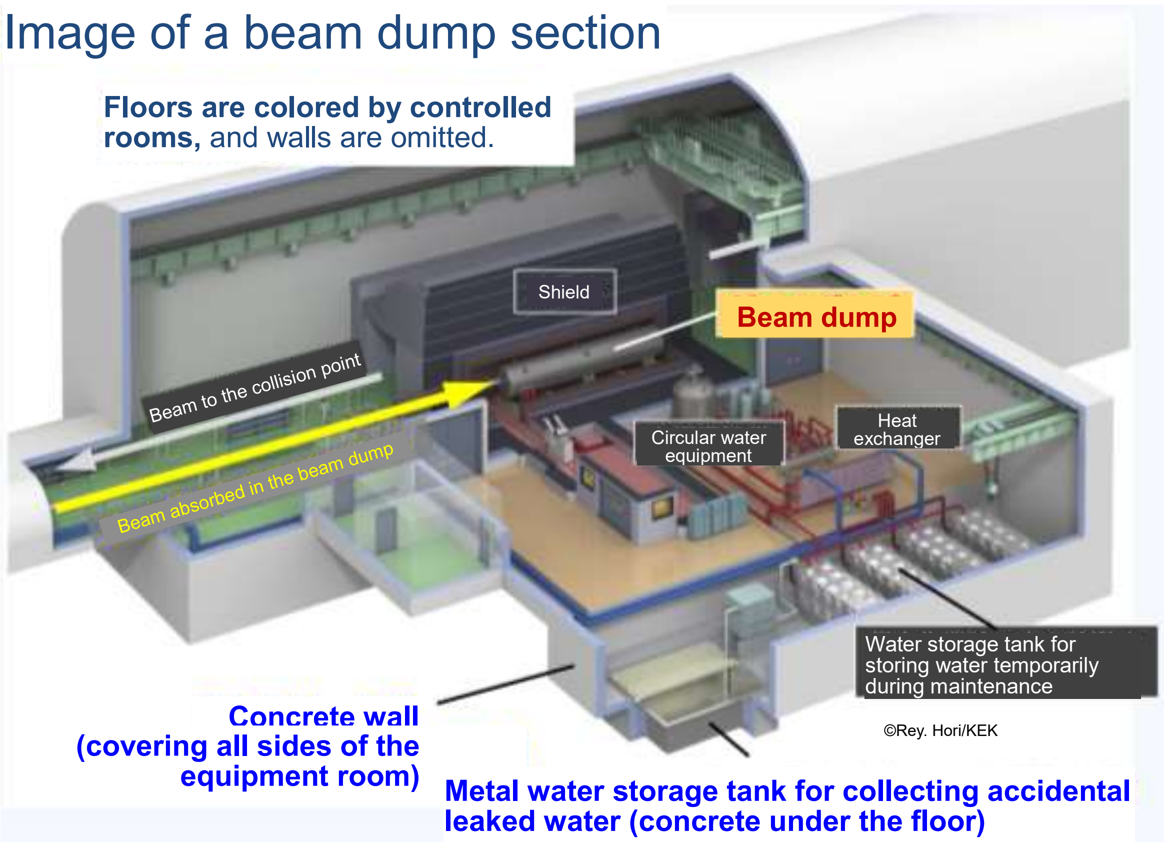
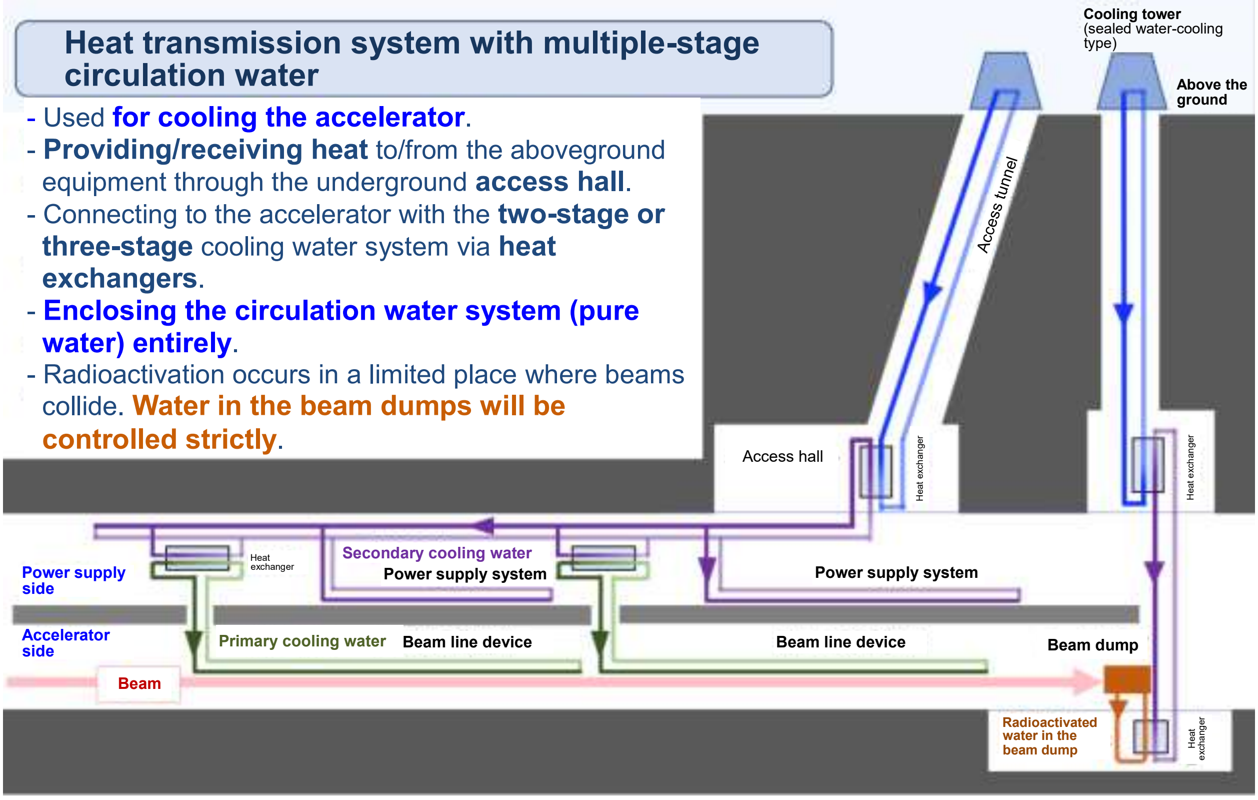


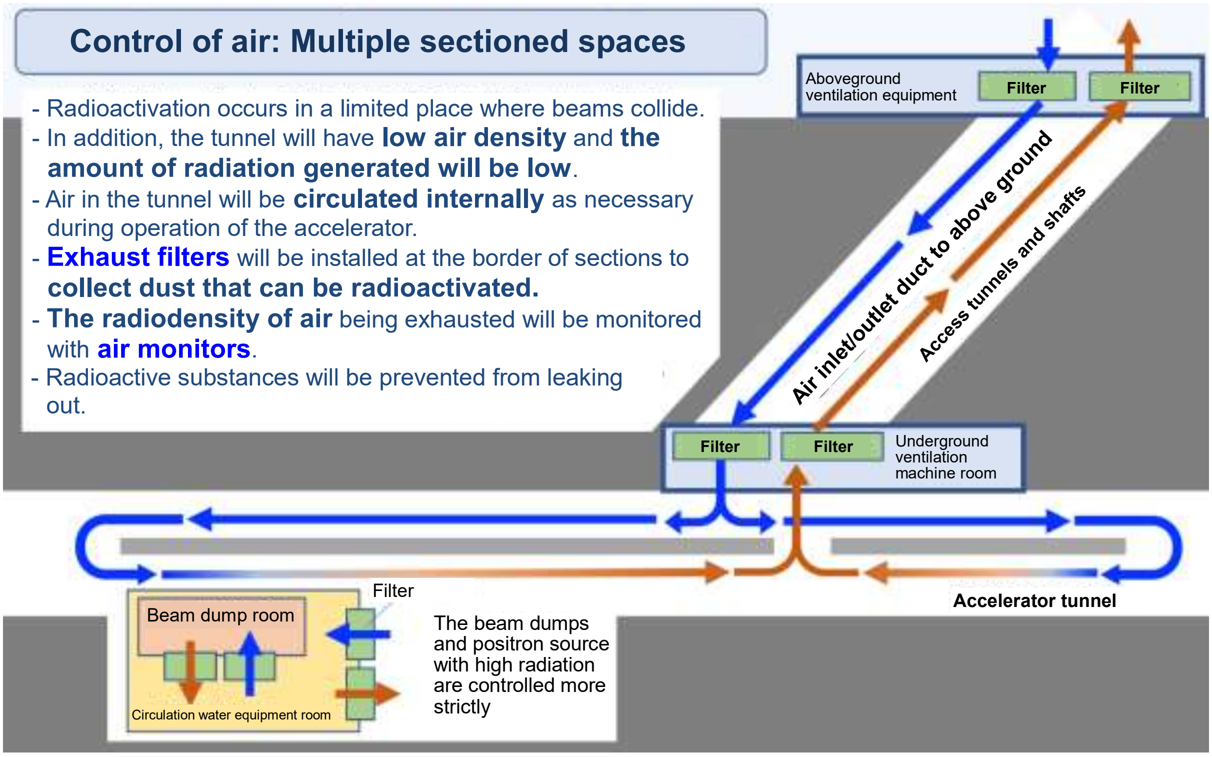
Image of a beam dump section

(4) Outline of the cooling water system



Circulation of cooling water

(5) Outline of the ventilation system



Circulation of air in the tunnel

(6) Measures for earthquakes and power outages

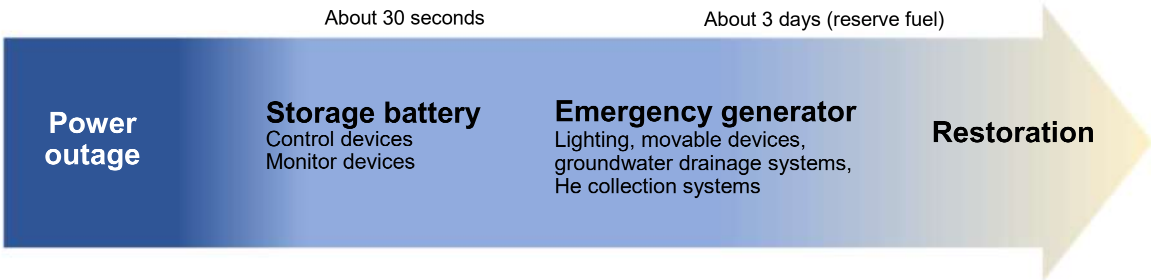
■ Safety systems stop beams.

Additional radioactivation will not occur. In addition, no radioactive substances requiring continuous cooling exist. The loss of power supply will not lead to radiation accidents.

■ The earthquake-proof design of devices is pursued.

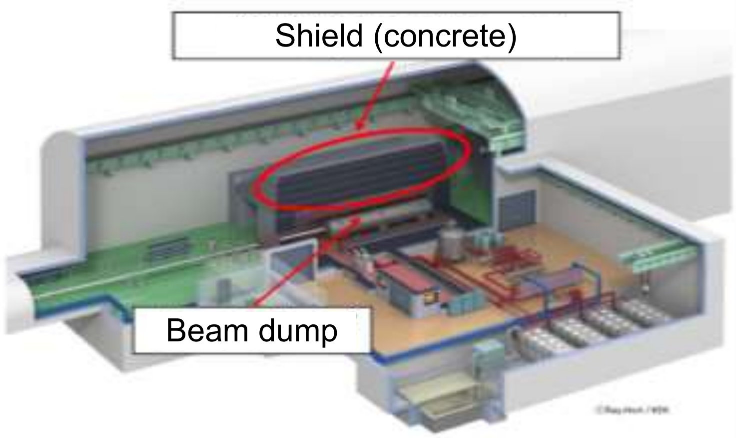
Shaking at 100 m under the ground is approximately 1/2 to 1/4 of that for the surface, so the facility becomes much safer.

Steps for a power outage



(7) Handling of radioactivated materials after the completion of experiments

- To prevent the radioactivation of tunnel floors and walls of the tunnel, shields will be added in advance.
- Devices to be used in other facilities will be stored temporarily while requests will be made for taking other radioactivated materials (including water in the beam dumps). Other disposal procedures, such as delivery to the “activity for burying waste from research facilities and laboratories” planned by the nation, are expected.
- Most of the other structures of the accelerator are non-radioactivated materials, so they are to be reused for other experiments.



©Rey. Hori/KEK

Article 1 Worldwide principal research institutes of elementary particle accelerators

■ In Japan, KEK (High Energy Accelerator Organization) in the City of Tsukuba has an operating circular accelerator with a circumference of 3 km. On the other hand, outside Japan, CERN (European Organization for Nuclear Research) near the border between Switzerland and France has an operating circular accelerator with a circumference of 27 km, the largest in the world.

■ In Germany, DESY (Deutsches Elektronen-Synchrotron) has an accelerator that passes through urban areas underground. On the other hand, the Fermi National Accelerator Laboratory in the U.S. attempts to harmonize with the natural environment by providing farmland, water accessible zones, and other natural areas on-site.

©2001-2020 CERN

European Organization for Nuclear Research (near the border between Switzerland and France)
(Circular (27 km in circumference), at approximately 100 m under the ground)

©KEK

High Energy Accelerator Organization (City of Tsukuba)
(Circular (3 km in circumference), at approximately 10 m under the ground)

©Fermilab

Fermi National Accelerator Laboratory (U.S.)
(Circular (6 km in circumference), at approximately 8 m under the ground)

©SLAC National Accelerator Laboratory

SLAC National Accelerator Laboratory (U.S.)
(Liner (3 km in length), at approximately 9 m under the ground)

©DESY/R. Schaaf und D. Schröder

Deutsches Elektronen-Synchrotron (Germany)
(Circular (6 km in circumference), at approximately 25 m under the ground)

III-2 Q&A: Questions of radiation

Q1. Is there any danger of radiation spread?

A1. Devices (solid) have no possibility of spreading radiation.
For cooling water and air, radiation spread will be prevented by multiple measures.

Radioactivation by the accelerator

- Though a part of the atoms in matter is radioactivated, most of them remain non-radioactivated. Thus, the shape of matter is unchanged.
- The possibility of spread **depends on the form of matter to be radioactivated (solid, liquid, or gas)**.

Devices composing the accelerator (solid)

- **Radiation is contained within matter, so it has no possibility of spreading.**

Cooling water and air in accelerator rooms (liquid and gas)

- Though radioactivation rarely occurs in most parts of the ILC, it will contain the following structures to prevent accidental radiation spread:
  - **Cooling water is operated in a multiple-stage circulation system.**
  - **Air is contained in the tunnel with multiple sectioned spaces and exhaust filters.**

Q2. Is water containing tritium in the beam dumps discharged into rivers?

A2. Water in the beam dumps will not be drained.

- If the ILC operates continuously for 20 years, **tritium with a maximum radioactivity of 100 trillion Bq** (0.3 g) is estimated to be accumulated in **approximately 100 tons** of water in the beam dumps.
- **Since water is circulated in controlled equipment rooms, it will not continue increasing.**
- **The amount of water can be sufficiently controlled** after experiment completion, so it is kept in storage containers until tritium decreases.
- Other disposal procedures, such as delivery to the “activity for burying wastes from research facilities and laboratories” planned by the nation, are additionally expected.

Q3. How much is 100 tons of water in the beam dumps?

A3. It corresponds to about two oil tank freight cars.

- **Each of the beam dumps can contain approximately 50 tons of water.**
- **A total of approximately 100 tons can be contained in two beam dumps for electrons and positrons.**
- **This amount can be maintained and controlled after experiment completion.**

50 tons of water corresponds to:

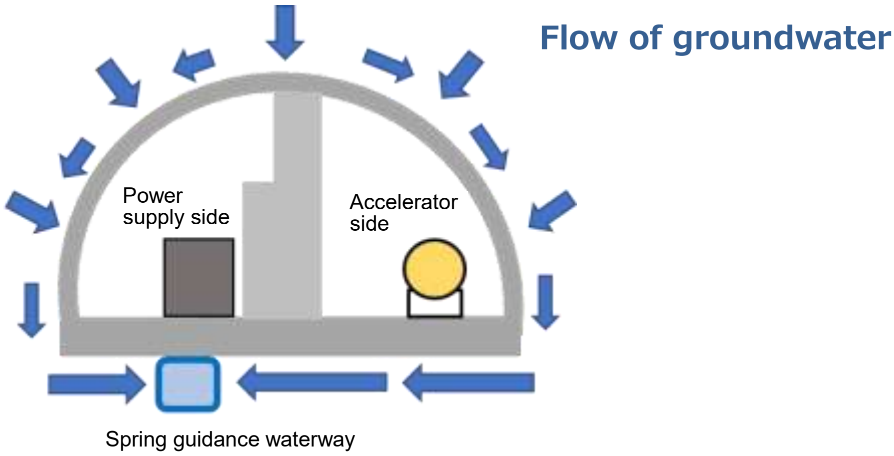
- A cubic volume of 10 m in width x 5 m in breadth x 1 m in depth
- About one oil tank freight car, for example

Taki type-1000 freight cars of Japan Freight Railway Company, each of which has an actual capacity of 61.6 m^3

Q4. Can groundwater be radioactivated in the tunnel?

A4. The ILC will have a structure where groundwater around the tunnel will not enter the accelerator tunnel.

- **When a beam smashes matter, radiation is generated and surrounding objects are radioactivated. Beams will not hit objects in most places in the ILC, so radioactivation may not occur.**
- **In places where beams hit objects, shields will be installed and the places will be covered locally to prevent the radioactivation of the surroundings.**
- **The ILC will be designed such that groundwater will not be radioactivated because it is outside the tunnel.**

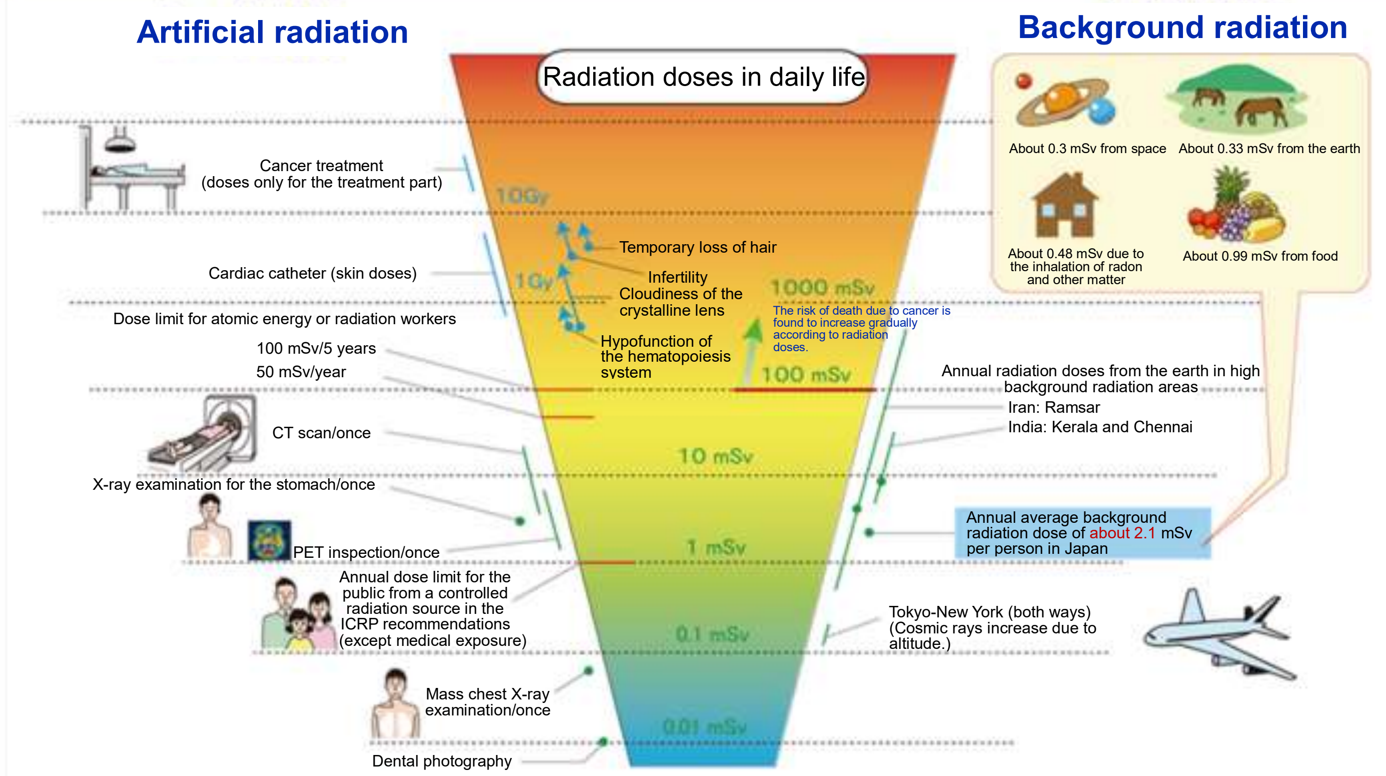


Typical cross section (image) of a main linac of the ILC tunnel

Article 2 Knowledge about radiation

Radiation in daily life

Comparison of radiation doses (simplified diagram)



Sources:
- The National Institute for Quantum Science and Technology prepared the diagram from the following materials (in May 2018):
- 2008 Report from the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)
- 2007 Recommendations from the International Commission on Radiological Protection (ICRP)
- Medical Exposure Guideline from the Japan Association of Radiological Technologists
- Radiation in Daily Life (Calculation of Public Radiation Doses): New Edition, etc.

mSv: millisievert

Source: Unified basic materials for impacts of radiation and other influences on human health (2019 fiscal year edition)

- A comparison of radiation doses to which humans are exposed in daily life shows that **most radiation doses for occasions such as CT scans and annual radiation doses are in units of millisieverts,** excepting special cases such as radiation treatments.
- Note that **a radiation dose of 100 millisieverts or more is considered to affect human health.**

Radiation in daily life

Natural radioactive substances in the body and food

Radioactive substances in the body

In case of a body weight of 60 kg:

Potassium 40	***1**	**4,000 Bq**
Carbon 14	***2**	**2,500 Bq**
Rubidium 87	***1**	**500 Bq**
Tritium	***2**	**100 Bq**
Lead and polonium	***3**	**20 Bq**

***1**: A nuclide from the origin of the earth
***2**: A nuclide derived from N-14 and other matter from cosmic rays
***3**: A nuclide in the uranium series from the origin of the earth

Concentration of a radioactive substance (potassium 40) in food

Rice **30**, Milk **50**, Beef **100**, Fish **100**, Powdered milk **200**, Spinach **200**, Potato chips **400**, Green tea **600**, Dried shiitake mushroom **700**, Dried tangle **2,000**

(in **Bq/kg**)

Bq: becquerel Bq/kg: becquerel/kilogram
Source: Prepared from "Research for Radiation Data in Daily Life (1983)" of the Nuclear Safety Research Association (a public utility foundation)

Source: Unified basic materials for impacts of radiation and other influences on human health (2019 fiscal year edition)

- Since potassium is contained in most food and 0.01% of it is radiopotassium, **almost all food contains radiopotassium**.

- Radiopotassium emits beta rays and gamma rays, so **ingesting food will lead to internal exposure.**

- Since the concentration of potassium in the body is kept constant, **radiation doses from potassium in food depends on body size.**

IV Why the ILC is unsuitable for the disposal of high-level radioactive waste

Q1. Will the ILC be a disposal plant for high-level radioactive waste?

A1. The ILC will not be a final disposal plant for high-level radioactive waste because of the following reasons:

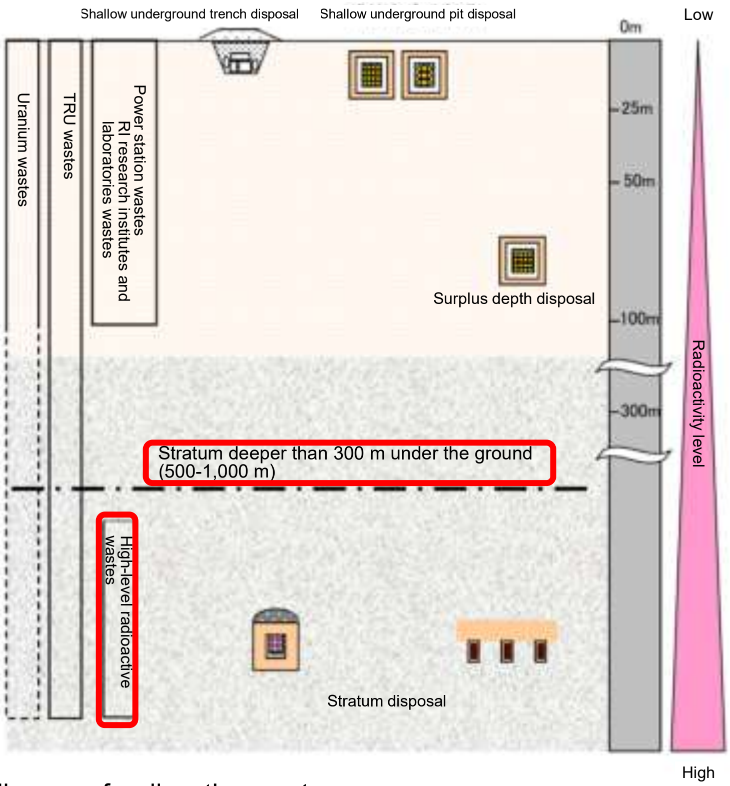
- **The structure of the ILC does not meet the structural requirements for final disposal plants for high-level radioactive waste.**
- **In addition, the law states that companies of disposal plants for radioactive waste must receive and respect the opinion of local governments sufficiently; Iwate Prefecture has repeatedly declared that it will not accept final disposal plants for radioactive waste.**

■ Requirements for final disposal plants for high-level radioactive waste, corresponding to first-class buried waste, specify that waste be buried at a stable area deep underground that is isolated from the human living environment and enclosed, and that artificial structures such as vitrified objects be installed at a depth of 300 m or more underground.

■ The ILC will be constructed at an altitude of approximately 110 m, and most parts of it will be at a depth of 50-100 m, close to the ground surface. Additionally, the shape of the facility is not suitable for burying waste; thus, the ILC does not meet the structural requirements.

Disposal methods for radioactive waste are classified into the following four methods depending on the depth and barriers to reduce the leakage of radioactive substances:

- **Shallow underground trench disposal**
  Burying waste in a shallow underground trench without artificial structures
- **Shallow underground pit disposal**
  Disposing of waste in a shallow underground concrete pit
- **Surplus depth disposal**
  Disposing of waste at a surplus depth (of 50-100 m under the ground) sufficient for regular underground usage
- **Stratum disposal**
  Disposing of waste in a stratum deeper than 300 m underground



How to dispose of radioactive waste

(Source: Materials from the 18th New Plan Decision Meeting of the Atomic Energy Commission, partially edited for explanatory reasons)

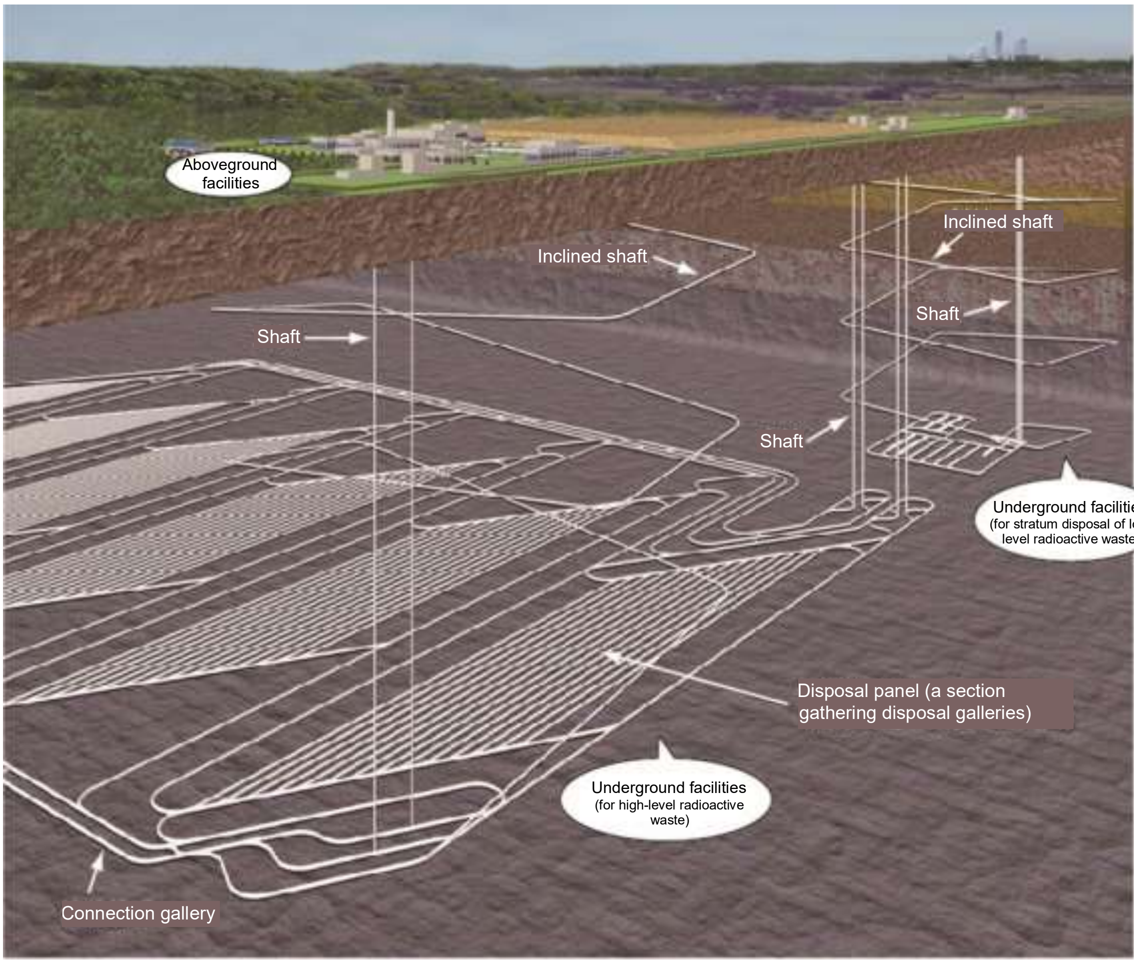
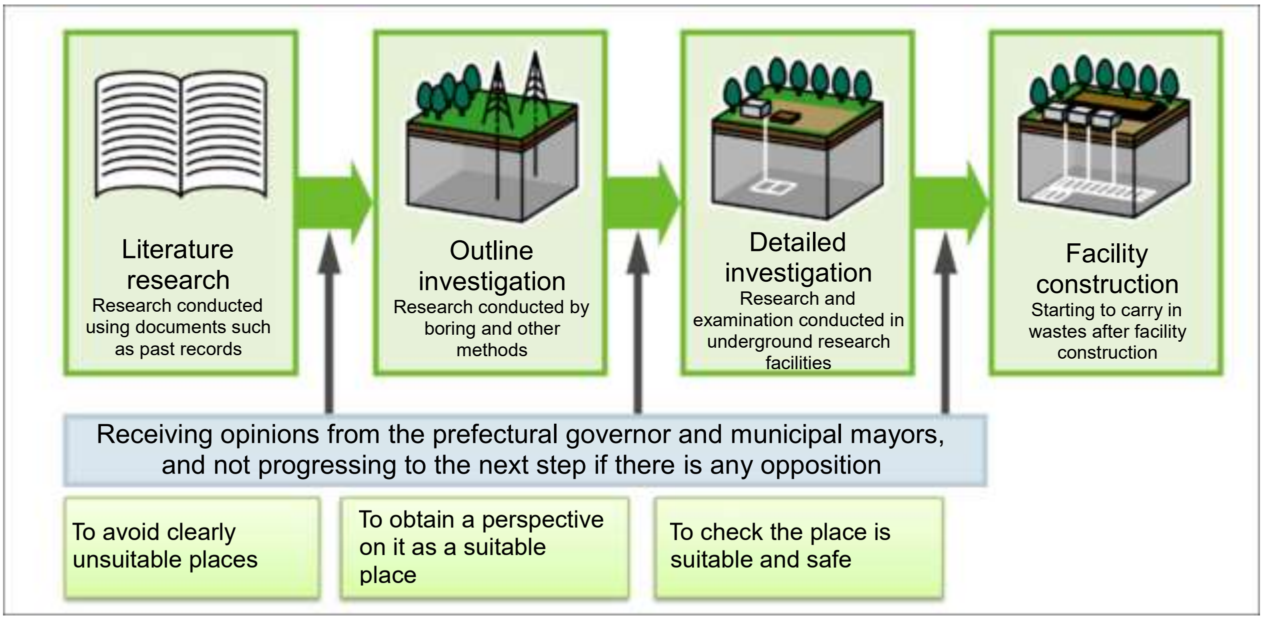


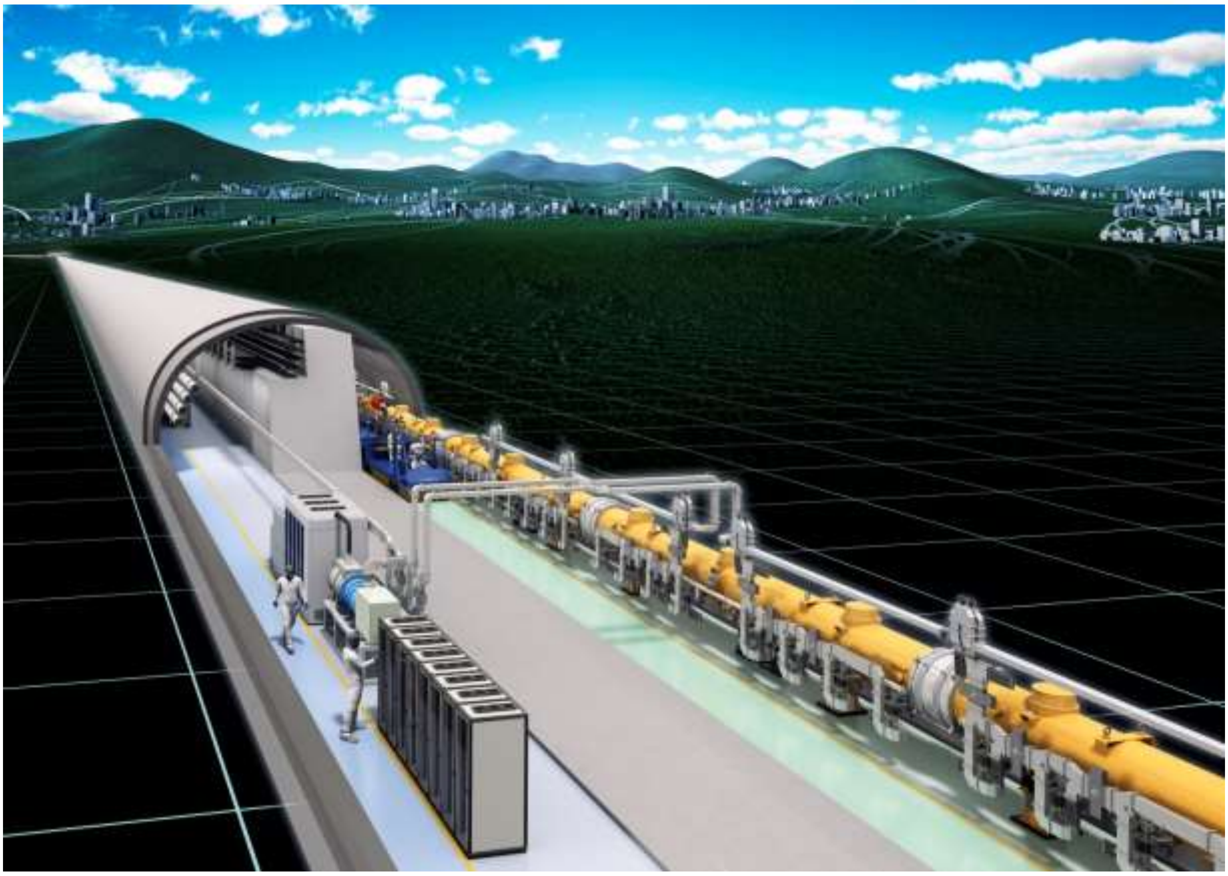
Image of geological disposal facilities

(Source: Web site of the Nuclear Waste Management Organization of Japan (NUMO))



Survey for disposal site selection

(Source: “Explanation reference materials for the interactive explanatory meeting all over Japan” of the Nuclear Waste Management Organization of Japan (NUMO))


©Rey. Hori/KEK

Prepared in June 2020