Simultaneous Satisfaction of Energy Resource Demand and Environmental Protection
-Nuclear Fission Energy System -

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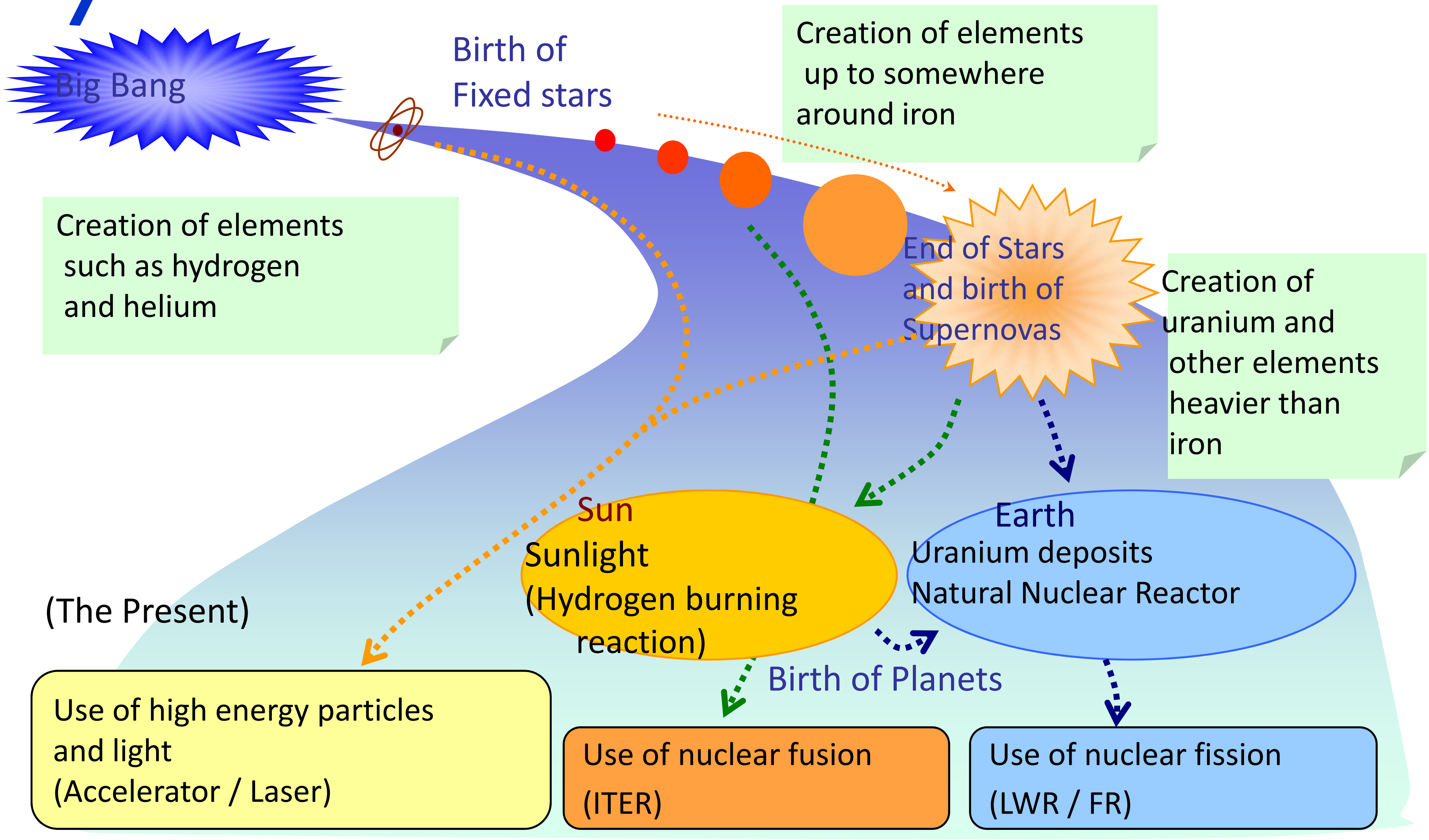
Creation of the Cosmos and an Energy Source



Big Bang

Birth of
Fixed stars

Creation of elements
up to somewhere
around iron

Creation of elements
such as hydrogen
and helium

End of Stars
and birth of
Supernovas

Creation of
uranium and
other elements
heavier than
iron

Sun
Sunlight
(Hydrogen burning
reaction)

Earth
Uranium deposits
Natural Nuclear Reactor

(The Present)

Birth of Planets

Use of high energy particles
and light
(Accelerator / Laser)

Use of nuclear fusion
(ITER)

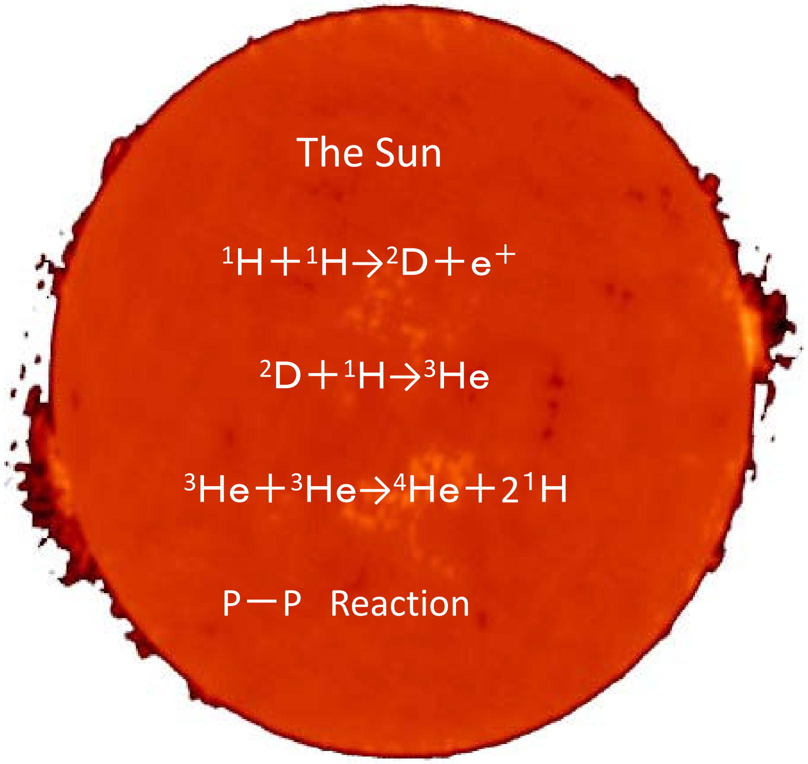
Use of nuclear fission
(LWR / FR)

Energy source on the earth

1 Joint work between Sun and Earth to form mild environment on Earth

- The sun radiates huge amount of energy 1.7x10 ** 11 to the space and 1/2x10**9.of them to the earth
- The energy changes on the earth to several forms like vapor, water- flow, wind thermal and chemical
- The earth is called as the water planet with mild environment of sea to enable the life to exist
- Bio-sphere with co-existence of plant and animals keeps eco-system for many years of mankind’s history

Nuclear Fusion Reactions in the Sun and the Solar Data as a Nuclear Energy System



The Sun

$^{1}H + ^{1}H \rightarrow ^{2}D + e^{+}$

$^{2}D + ^{1}H \rightarrow ^{3}He$

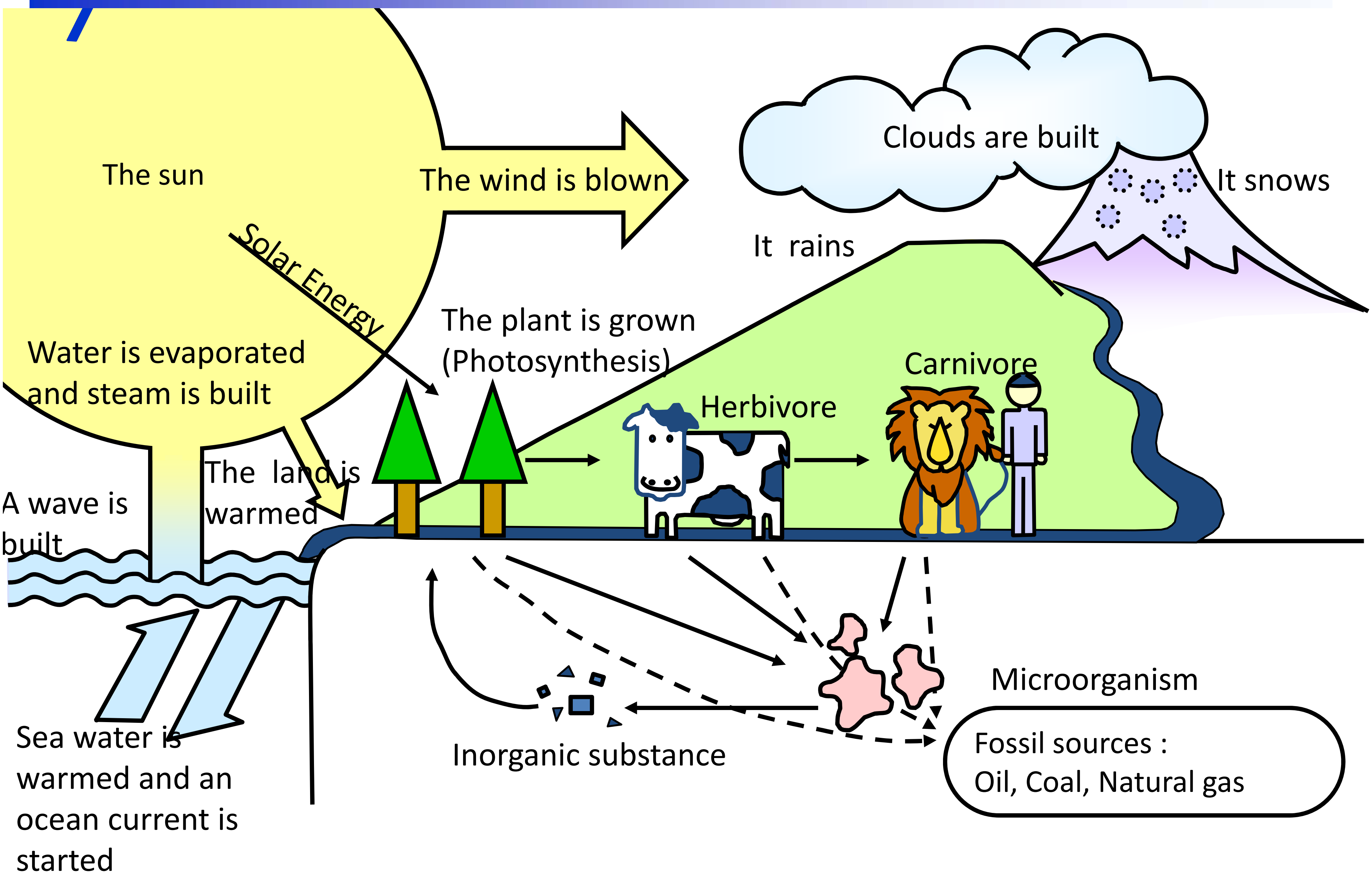
$^{3}He + ^{3}He \rightarrow ^{4}He + 2\,^{1}H$

P－P Reaction

<u>Solar Data as a Nuclear Energy System</u>

- Core Temperature; 1.58 x 10^{7} degree C.
- Core Pressure; 2.40 x 10^{11} atm
- Core Density; 1.56 x 10^{5}kg/m3, 14 times higher than lead
- Total Emission Energy; equivalent to 1 x 10^{17} units of 1000MWe nuclear power plants

Circulation of Solar Energy



2. Solar to Chemical energy to form Bio-Sphere by Photosynthesis

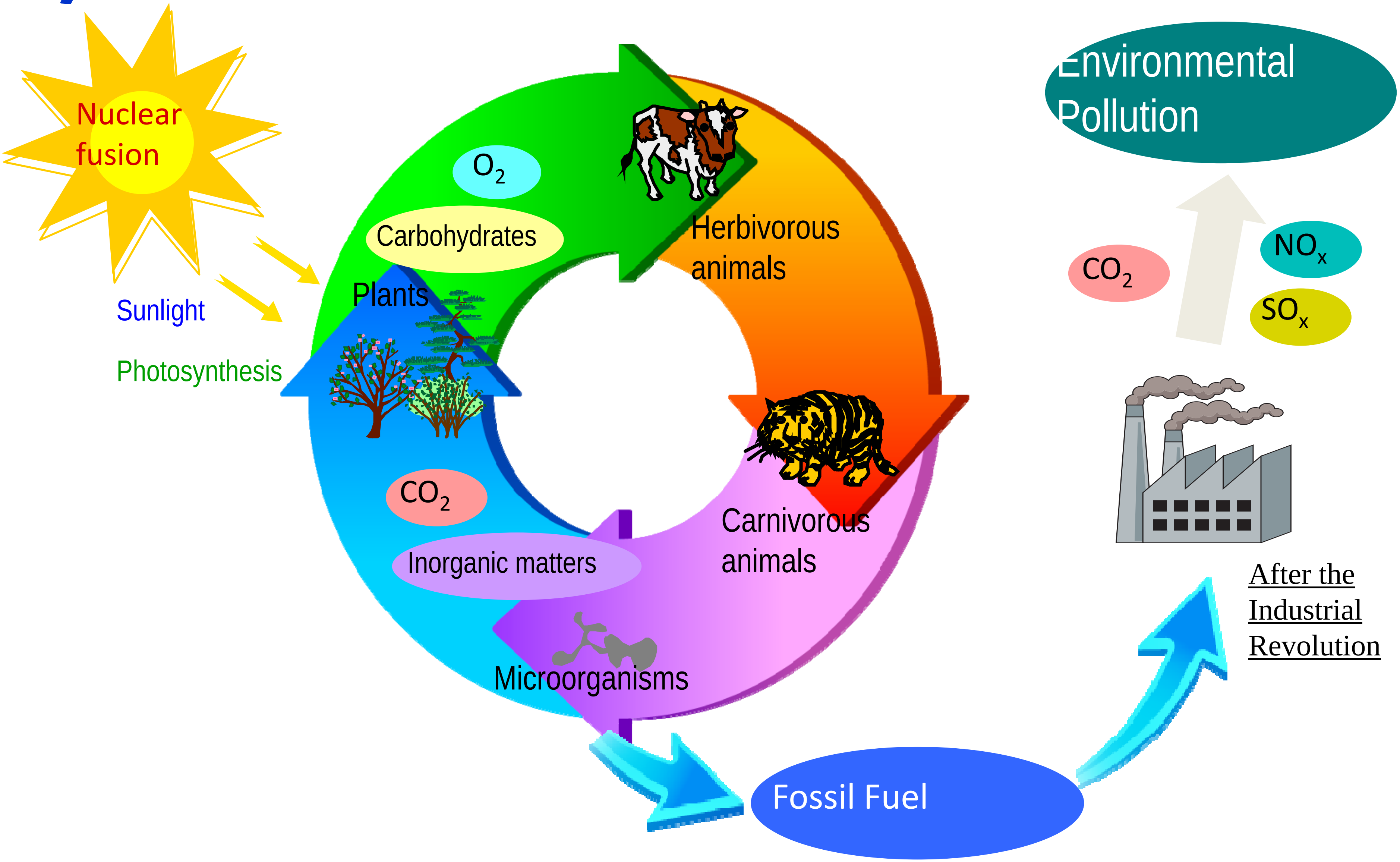
- Formation of Bio-sphere realized the civilization based on the chemical reaction

3. Industrial revolution touched on the fossil energy

It reversed the trend in the natural environment to increase carbon dioxide in the atmosphere.

The civilization based on the chemical reaction comes to the turning point

Bounty from the Sun and Ecological System



Nuclear fusion

Sunlight

Photosynthesis

O_2

Carbohydrates

Plants

CO_2

Inorganic matters

Herbivorous animals

Carnivorous animals

Microorganisms

Fossil Fuel

After the Industrial Revolution

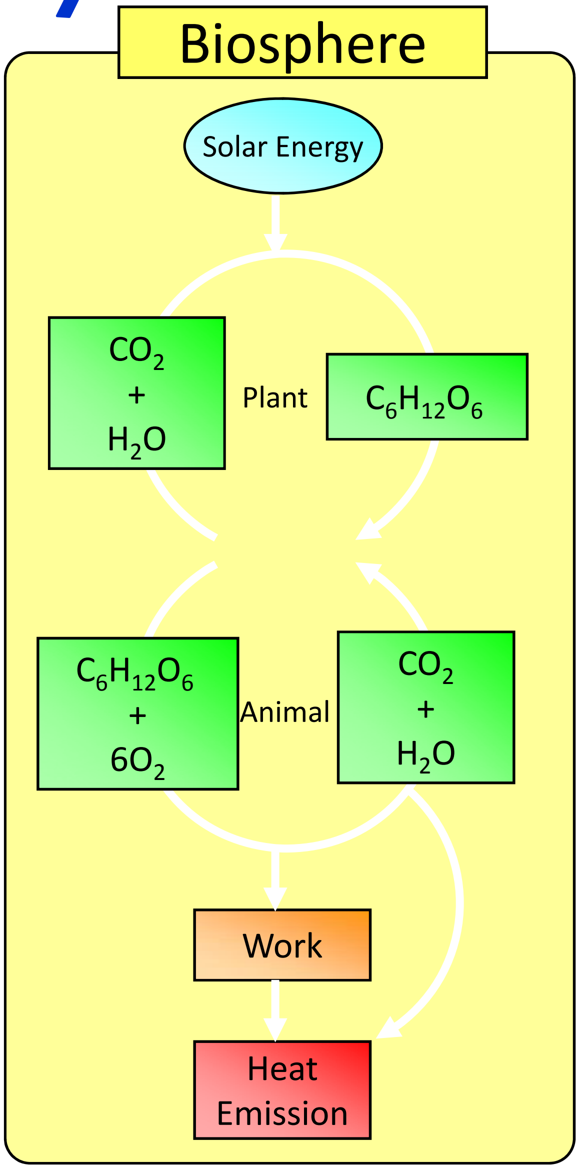
CO_2

NO_x

SO_x

Environmental Pollution

Energy System in Biosphere and Technical Field



Biosphere

Solar Energy

$CO_2 + H_2O$

Plant

$C_6H_{12}O_6$

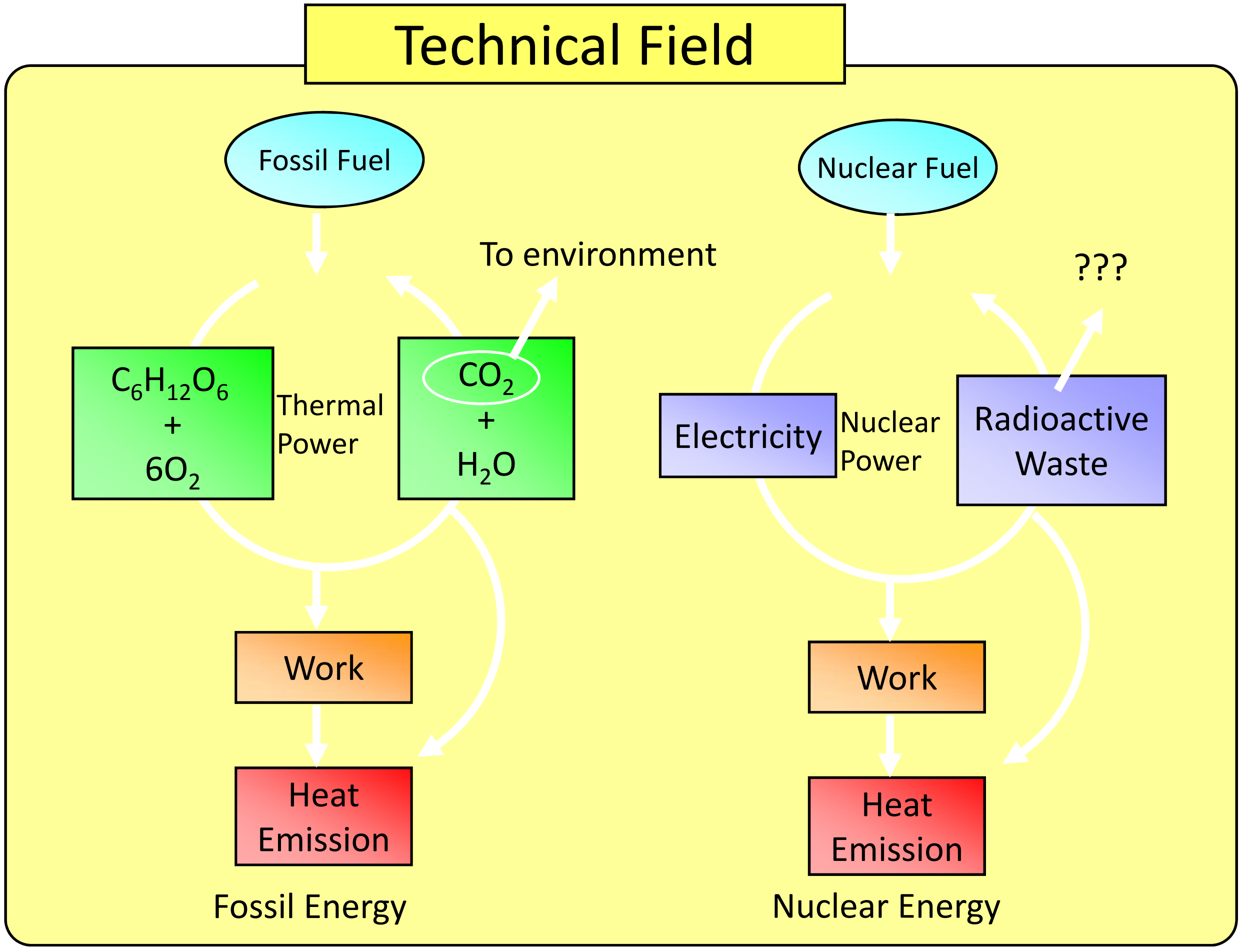
$C_6H_{12}O_6 + 6O_2$

Animal

$CO_2 + H_2O$

Work

Heat Emission



Technical Field

Fossil Fuel

To environment

$C_6H_{12}O_6 + 6O_2$

Thermal Power

$CO_2 + H_2O$

Work

Heat Emission

Fossil Energy

Nuclear Fuel

???

Electricity

Nuclear Power

Radioactive Waste

Work

Heat Emission

Nuclear Energy

	Fossil	Nuclear (Fast Reactor)
Fuel	Coal : 2,200,000 ton	Natural U : 1 ton
Waste	CO_2 : 6,000,000 ton	Vitrified HLW : 5 ton

For electric power generation of 1GWeYear

4. Lessons learnt from the past to the future nuclear era

- １. Industrial revolution began to use fossil fuel underground
- ２. Consumption of fossil energy induces the environmental problem to ask the necessity of changing energy resources
- 3.Harmonization rather than utilization shall be requirement for future civilization
- 4.Let’s consider nuclear fission energy system

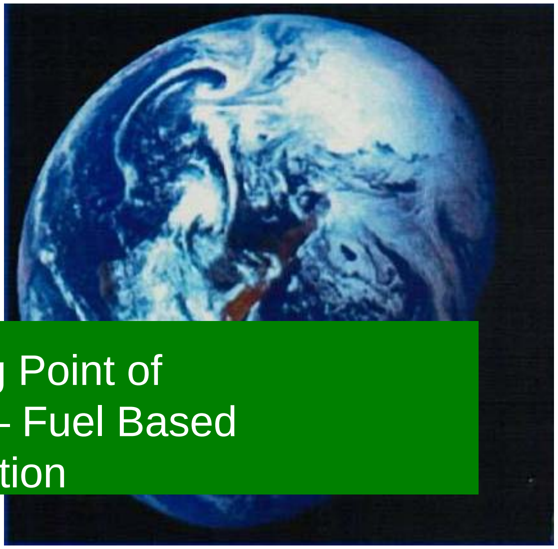
Requirements for Science & Technology in the next century

Utilization to Harmonization

Industrial Revolution
- Diversification of resources
- Mass consumption of energy

By-Products :
NOx, Sox, etc.

Global warming
by CO_2 emission



Turning Point of
Fossil – Fuel Based
Civilization

Restricting Unlimited Use of
Fossil Resources
- Ethics based on harmonization
- Regulation
- Technical countermeasures

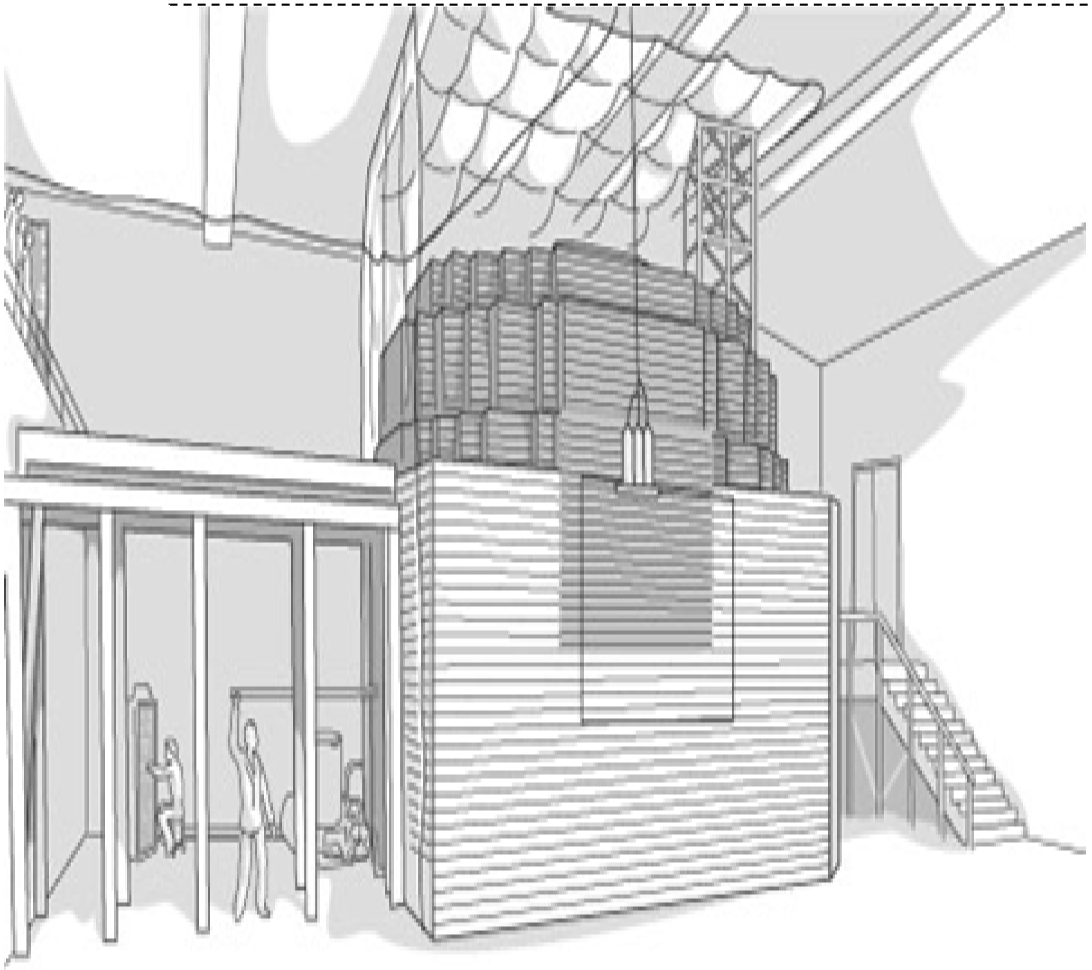
Requirements for Future Science & Engineering

Will it be a balanced and comprehensive technology ?
- provide new knowledge to the human society
- develop new fields of science and technology
- accept and support the civilization
- harmonize with the environment and society

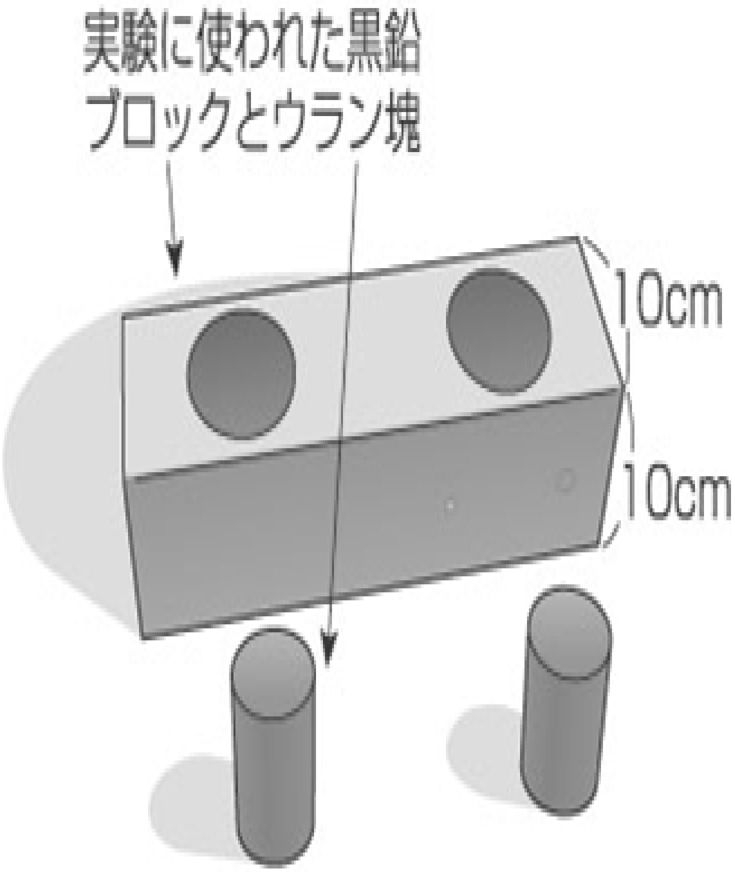
Nuclear fission energy as the planet energy

- 1. CP-1 succeeded in the first chain reaction on Dec. 2, 1942 at the University of Chicago
- 2. Natural fission reactors (water moderated and cooled) are found at Oklo uranium mine in Gabon Republic with small scale like a few hundred kilowatt in 1972.
- 3. Light water reactor has been developed and commercialized with excellent safety record

Chicago Pile　1

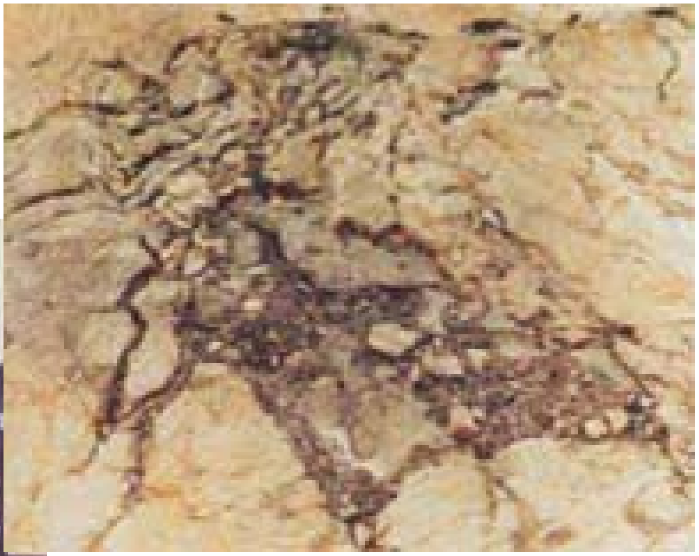


シカゴパイル第1号



Learn from Natural Fission Reactors

The traces of natural fission reactors discovered at Oklo
in Gabon



1. Self-controllability of reactor
2. Radioactive wastes can be enclosed within the deposit.
3. Decay of radioactivity within the deposit

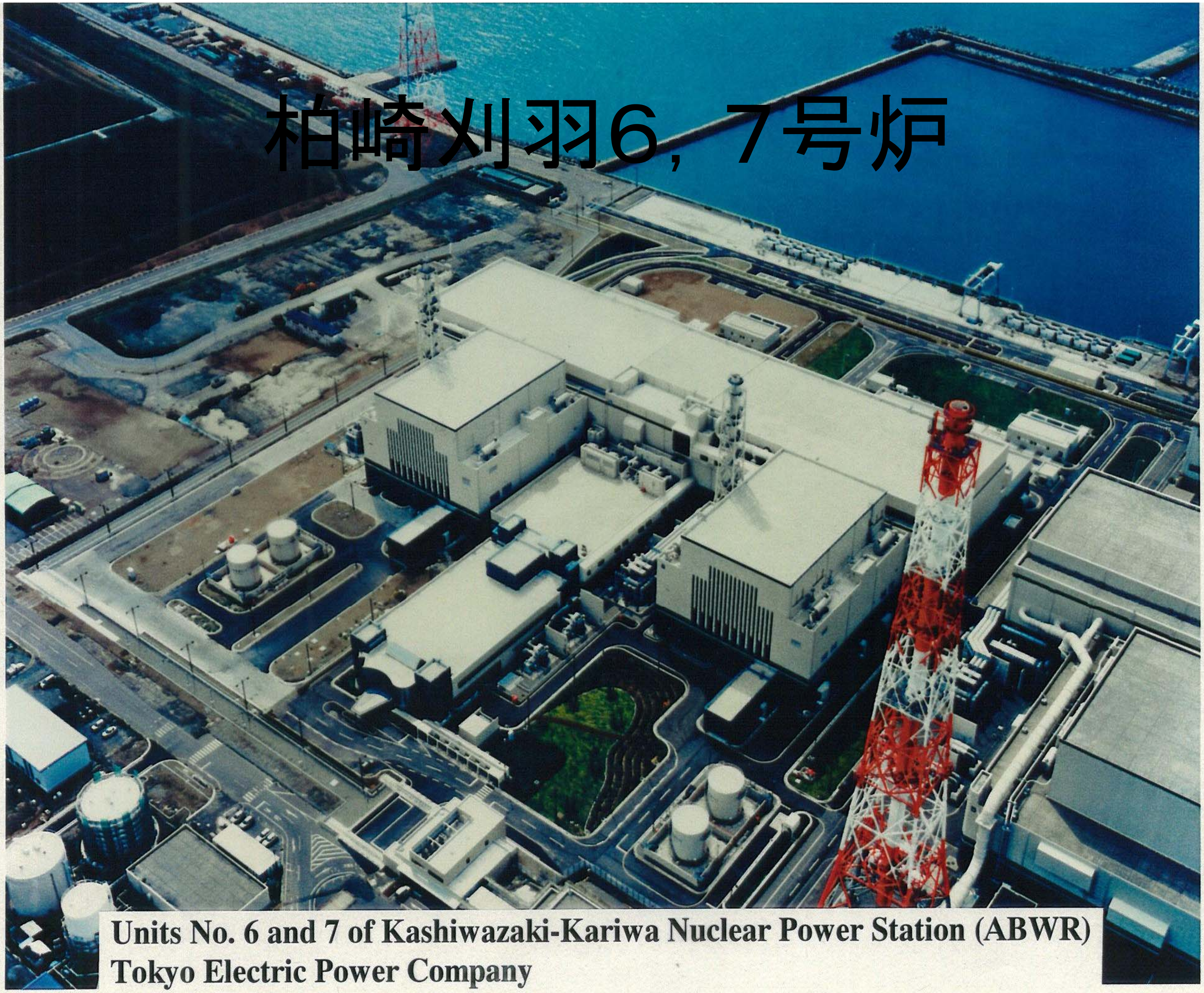
5. To secure nuclear energy resources in the future,

1. Step by step development
   - Light Water Reactor with good safety record
   - High Temperature Reactor HTTR for Chemical Energy Resource
   - Fast Reactor Joyo, Monju to JSFR
   - Nuclear Fuel Cycle with Separation and Transmutation of MA and LLFP

They are in line to the goal

2.To satisfy the resource demand and environmental protection simultaneously
   - 5objectives to be satisfied
   - SCNES system

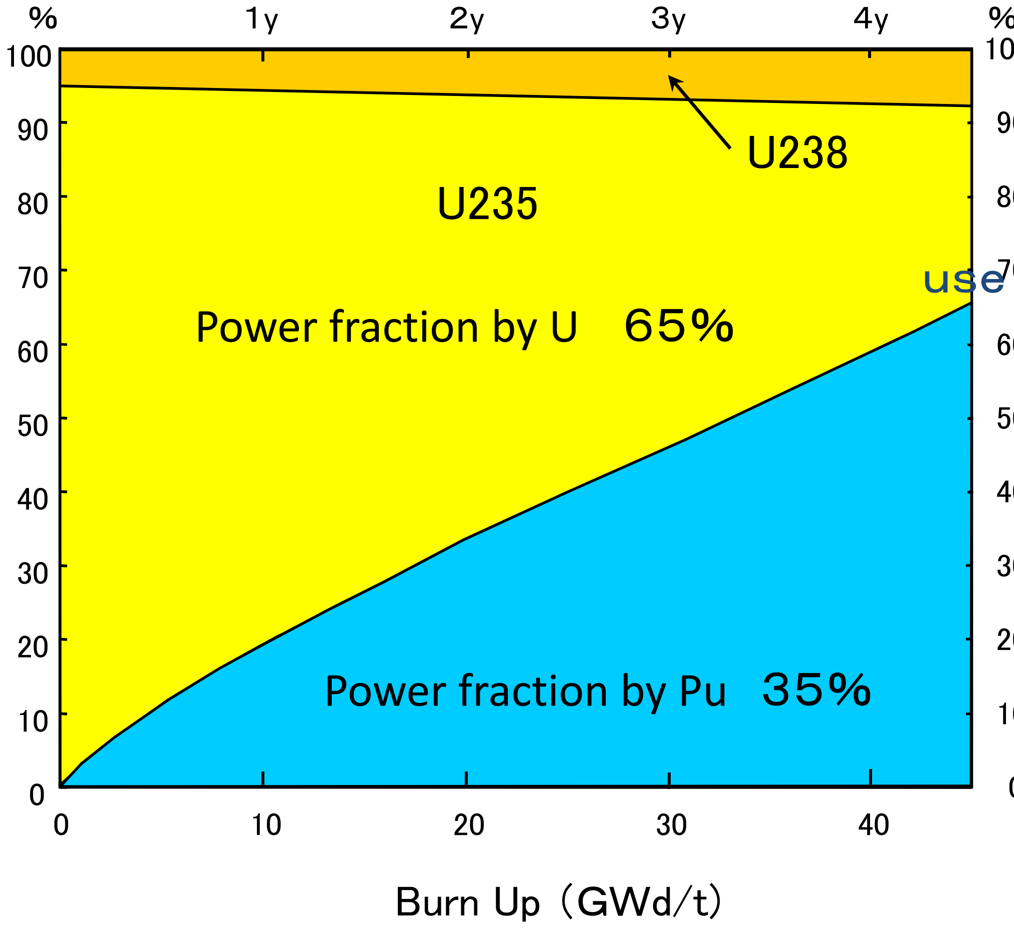
柏崎刈羽6，7号炉



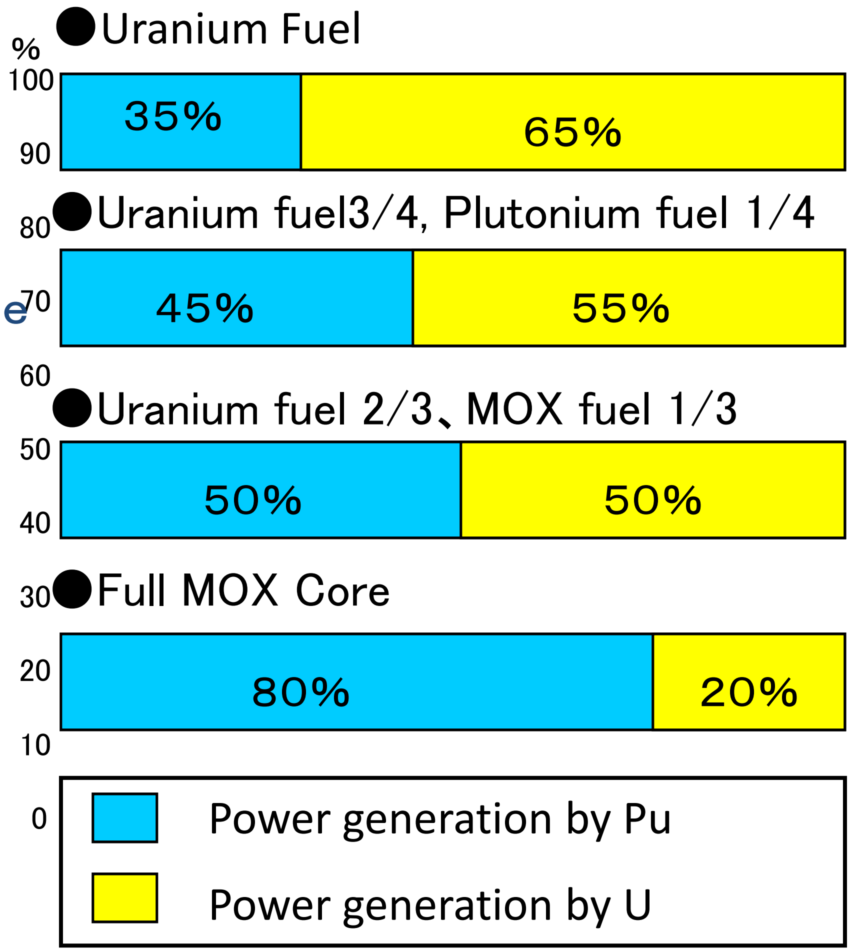
Units No. 6 and 7 of Kashiwazaki-Kariwa Nuclear Power Station (ABWR)
Tokyo Electric Power Company

Efficient MOX Use in LWR

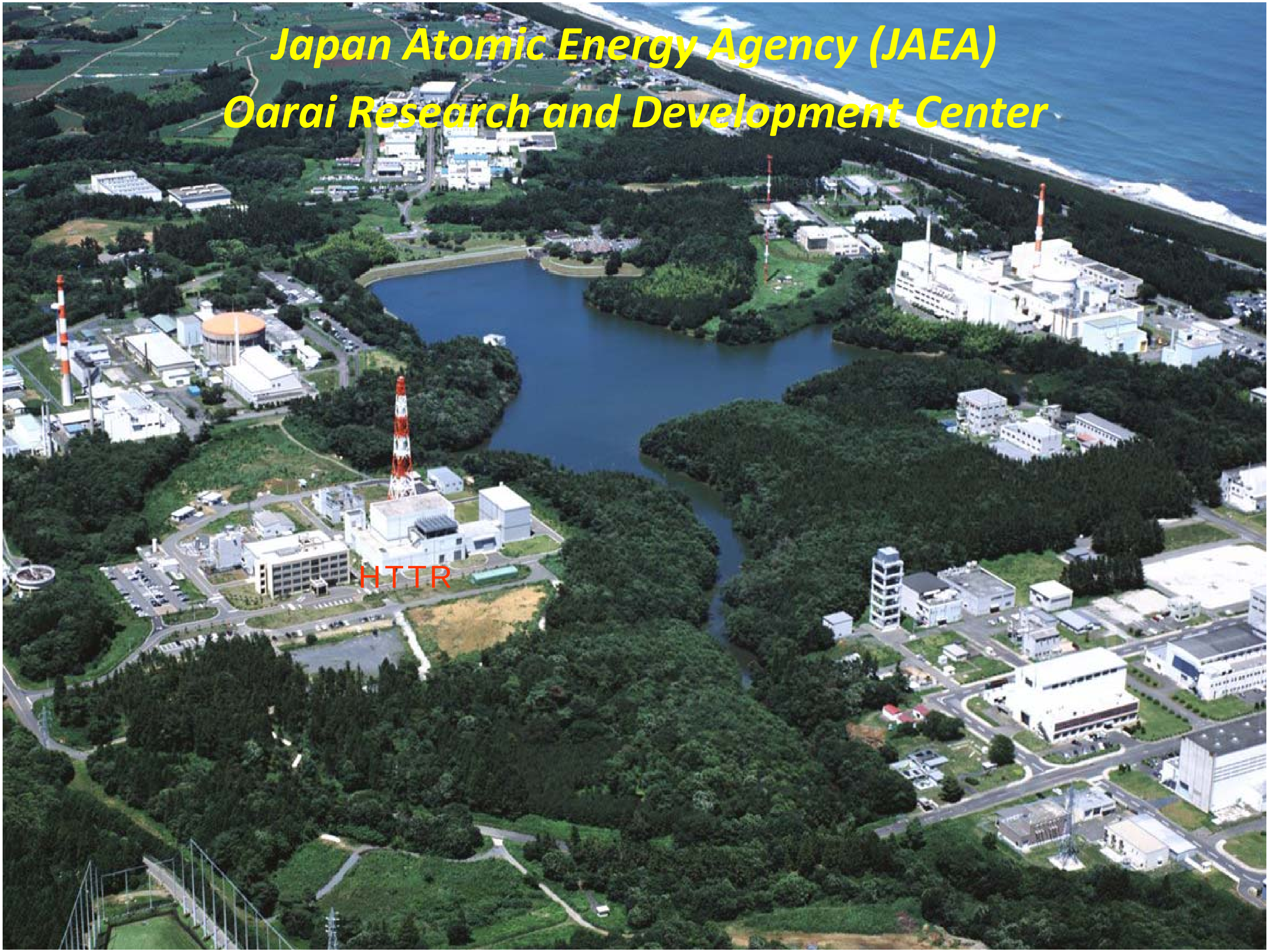
Fraction of Power generation by plutonium



Power generation ratio between Uranium and Plutonium

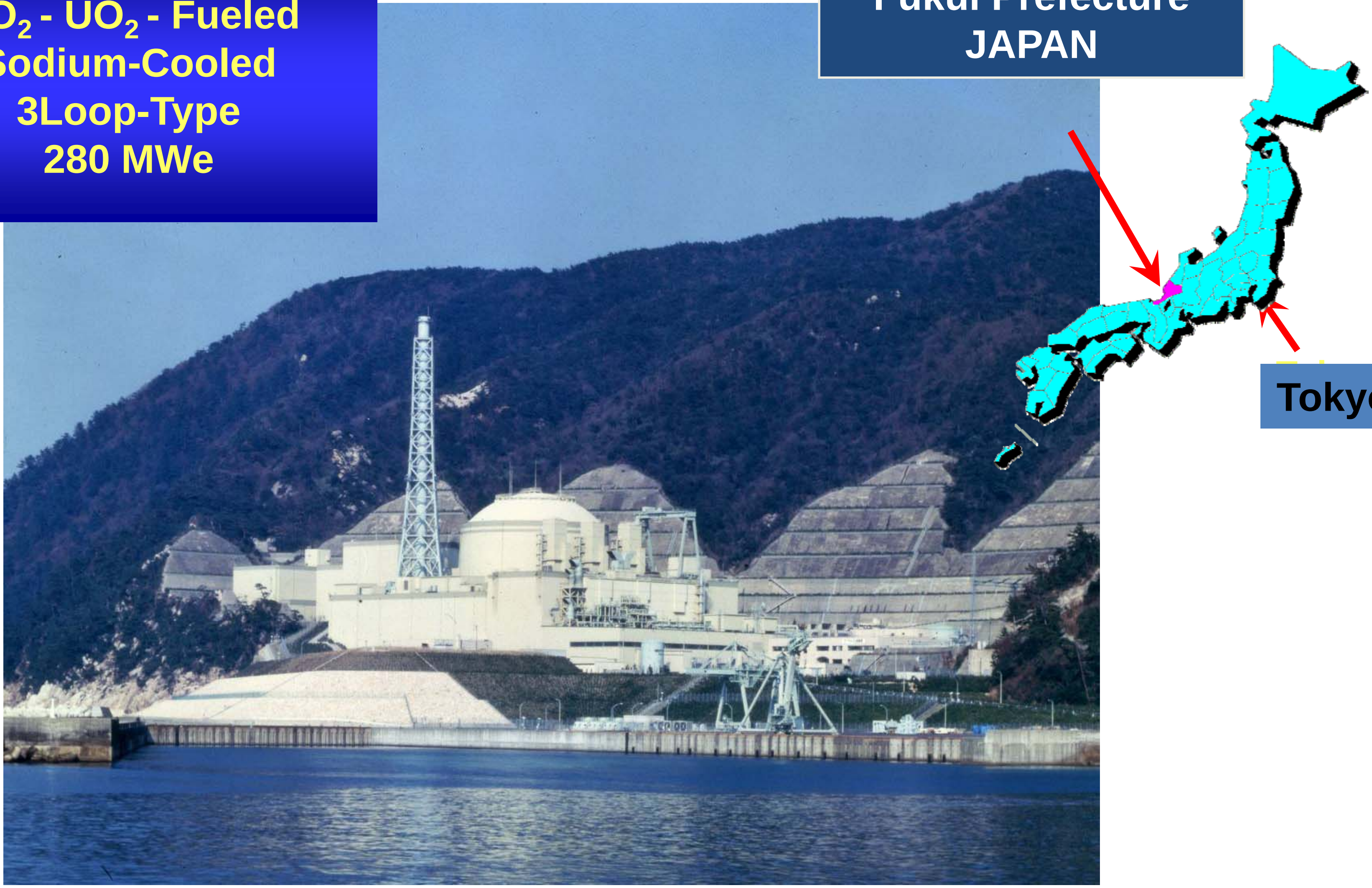


Japan Atomic Energy Agency (JAEA)
Oarai Research and Development Center



Prototype Fast Reactor “Monju”

PuO_2 - UO_2 - Fueled
Sodium-Cooled
3Loop-Type
280 MWe

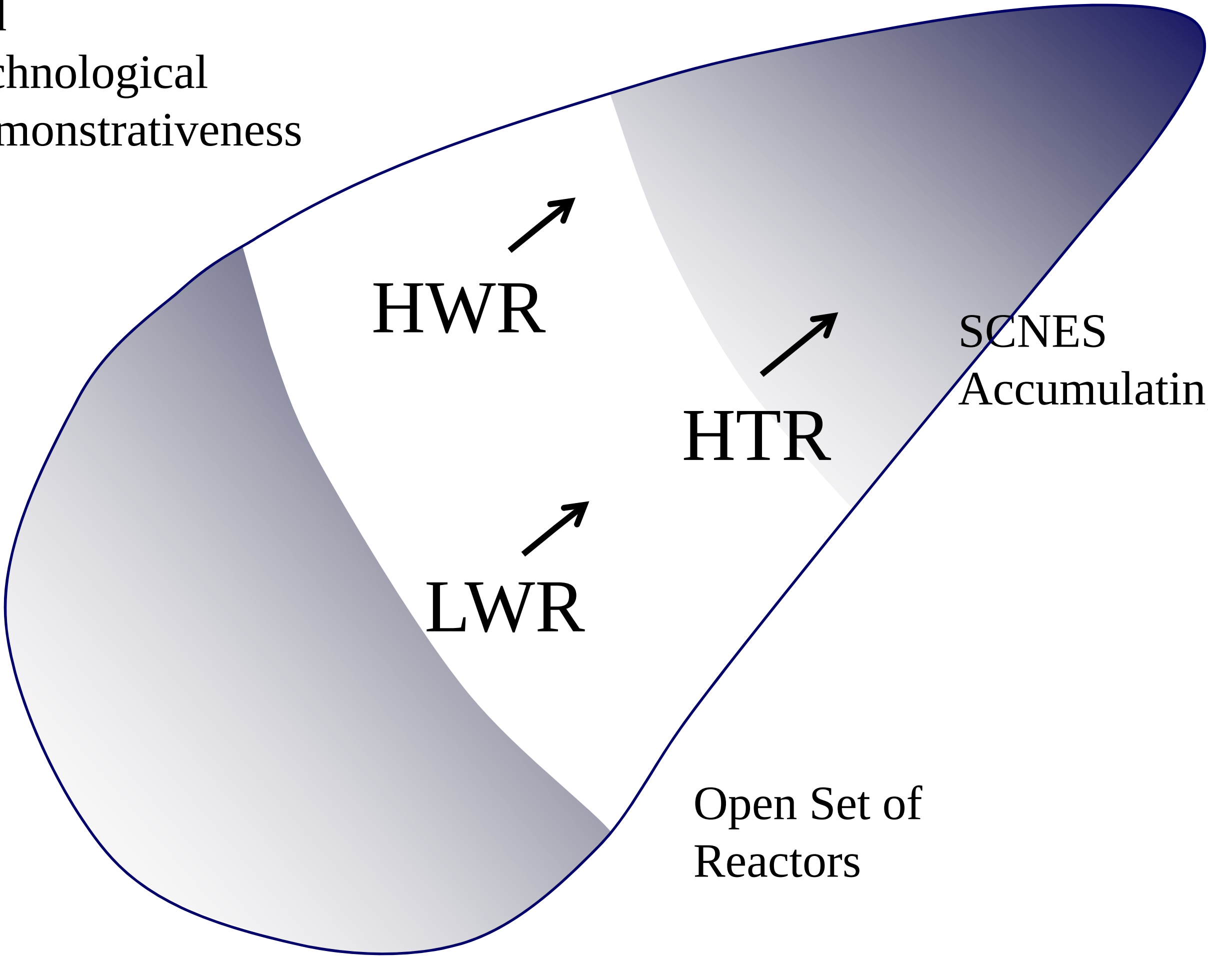


Fukui Prefecture
JAPAN

Tokyo

Way to SCNES

Scientific Feasibility
and
Technological
Demonstrativeness



HWR

HTR

LWR

SCNES
Accumulating point

Open Set of
Reactors

6. For simultaneous satisfaction of resource demand and environmental protection

Future nuclear fission energy system should the 5 objectives simultaneously within the assets of nuclear fission reaction .

Neutron yield of 2.9 and energy release of 200Mev

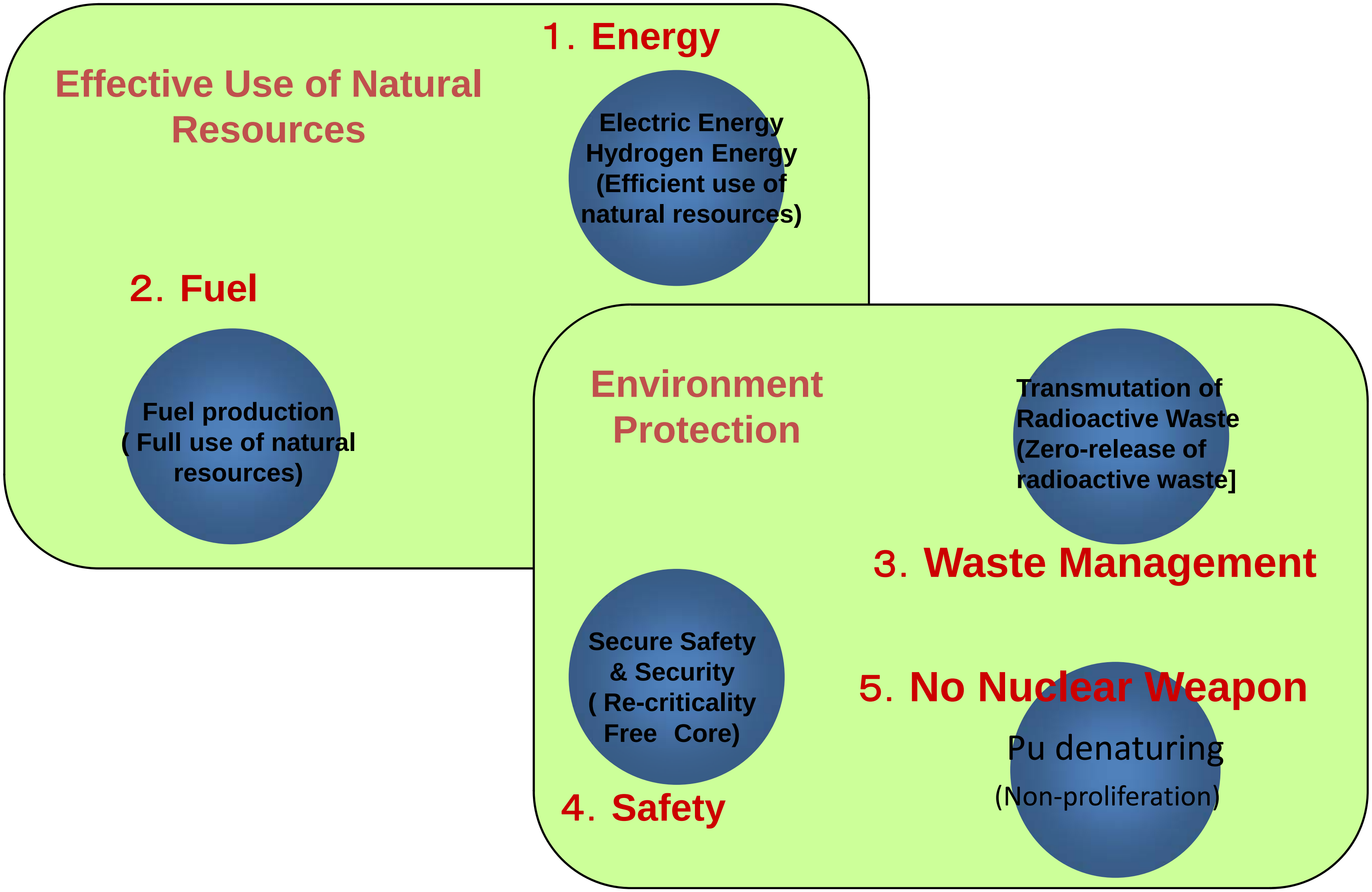
For Resource Demand

(1)energy production,
(2)fuel production

For Environmental Protection

(3)transmutation of radioactive substance, mainly fission products
(4) safety and
(5) non-proliferation.

Nuclear Energy System with 5 Objectives satisfied Simultaneously



1. Energy

Effective Use of Natural Resources

Electric Energy
Hydrogen Energy
(Efficient use of natural resources)

2. Fuel

Fuel production
(Full use of natural resources)

Environment Protection

Transmutation of Radioactive Waste
(Zero-release of radioactive waste]

3. Waste Management

Secure Safety & Security
(Re-criticality Free Core)

4. Safety

5. No Nuclear Weapon

Pu denaturing
(Non-proliferation)

Energy Balance

Items		Energy （MeV／fission）	
Produced Energy	1. fission reaction		
	thermal energy	Ef	200
Consumed Energy	1. Energy loss at power plant		
	energy loss due to conversion	Er1	118
	other consumptions	Er2	8
	2. Energy loss at fuel cycle		
	reprocessing & fabrication	Ec1	< 0.2
	LLFP nuclide separation	Ec2	< 1
	LLFP multi-recycling	Ec3	< 0.1
Usable Energy	1. Obtained energy		
	electricity	Ee	73

Neutron Balance

		ケース			
		Fast Reactor		Thermal Reactor	
		MOX Fuel	Metal	MOX Fuel	
Neutron Yield /fission		2.9	2.9	2.9	
	For Chain Reaction	1.0	1.0	1.0	
	Capture by Fissile Material	0.2	0.13	0.4	
	Fuel Production	1.0	0.85	(1.3)	Conversion Ratio ＝1
	Parasitic Absorption	0.25	0.20	0.25	Structure Material Coolant Material
	Available Number of Neutron for Transmutation of MA and LLFP	0.45	0.72	Negative	

Future Nuclear Energy System needs
Fuel Cycle with Isotope Separation

A Nuclear Fission generates about 2.9 neutrons
- for chain reaction needs 1 neutron
- for fuel production needs more than 1 neutron
- for transmutation of radioactive FP needs about 0.6 neutron
(considering neutron absorption and leakage)

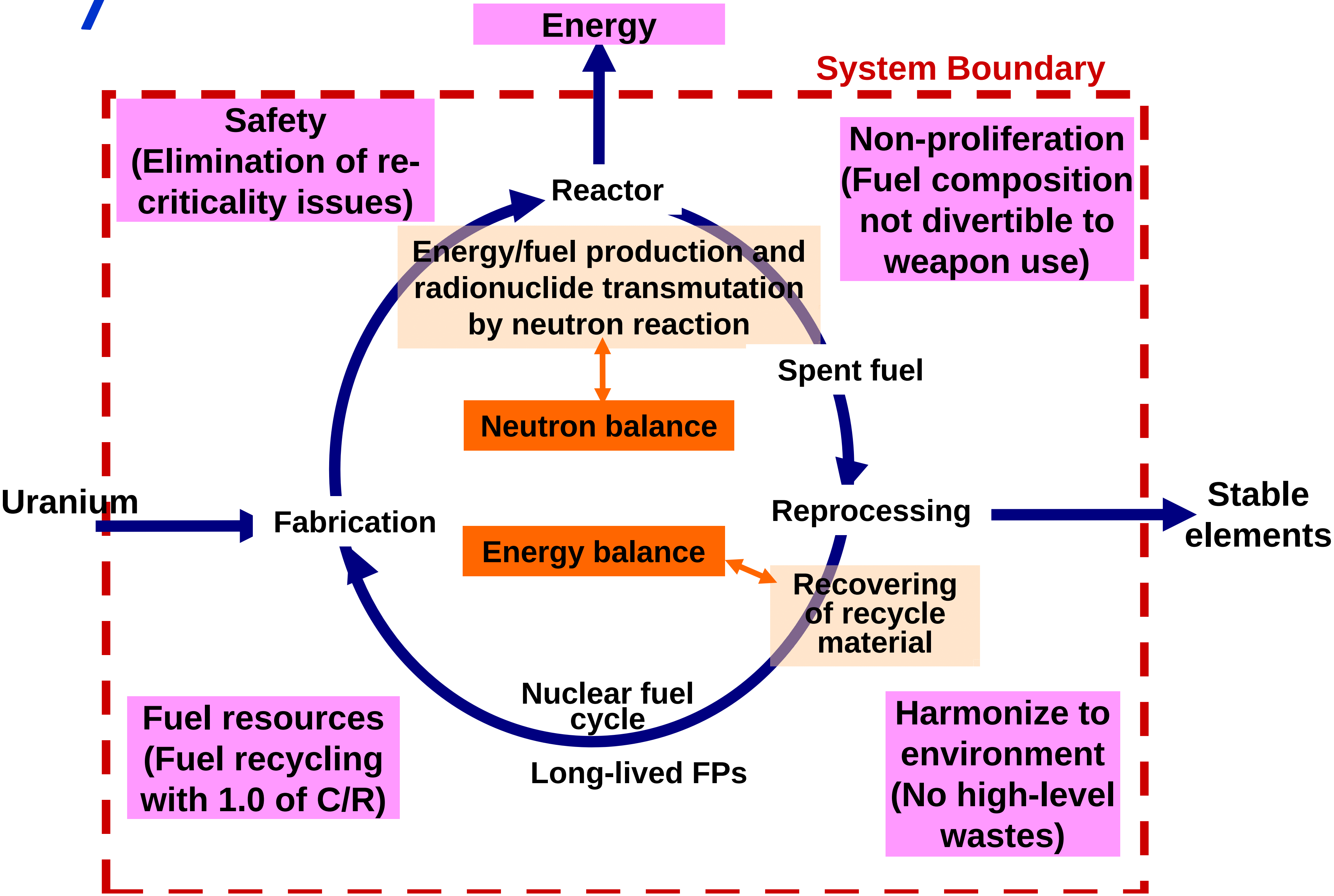
Isotope separation below makes it possible

FP $T_{1/2}$ lower limit（Year）		1	3	10	20	30	100	200	2000	50000
Absorption (n/fiss.)	Element-wise Separation	6.78	2.07	1.99	1.23	1.12	1.07	0.95	0.95	0.95
	Isotope-wise Separation	0.25	0.24	0.24	0.24	0.24	0.22	0.22	0.22	0.22

SCNES Concept and Mass flow SCNES should have nuclear fission reactor system and nuclear furl cycle system together

- In reactor system side we take the neutron balance into consideration to attain the objectives of energy / fuel production and transmutation of radionuclide
- In fuel cycle side energy is fed for fuel fabrication and reprocessing
- In SCNES system uranium is fed to the system and only stable elements are discharged from it in addition to energy delivery .

SCNES Concept and its Target（use of fission assets ）



Energy

System Boundary

Safety
(Elimination of re-criticality issues)

Reactor

Non-proliferation
(Fuel composition not divertible to weapon use)

Energy/fuel production and radionuclide transmutation by neutron reaction

Spent fuel

Neutron balance

Uranium

Fabrication

Reprocessing

Stable elements

Energy balance

Recovering of recycle material

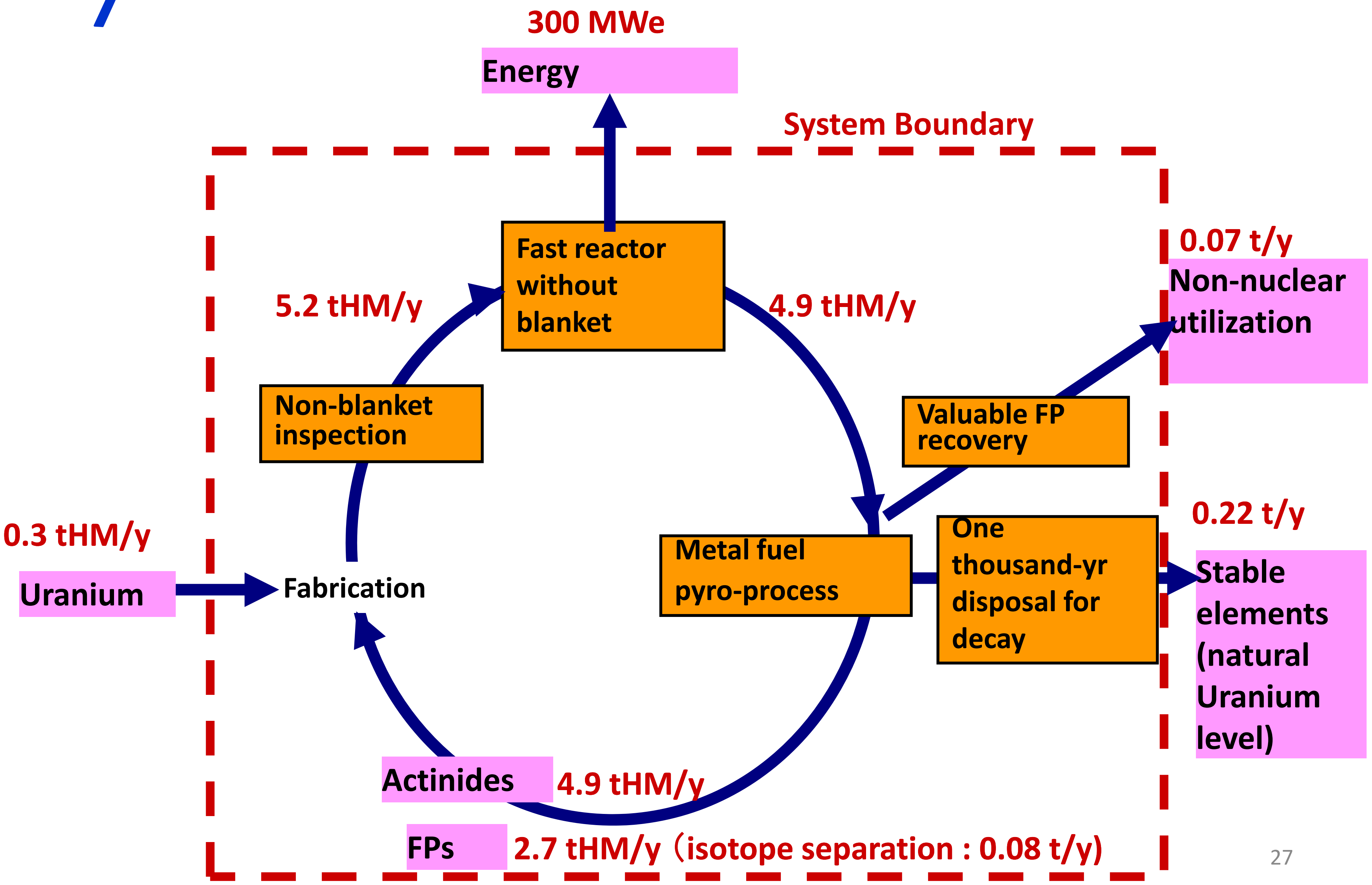
Nuclear fuel cycle

Fuel resources
(Fuel recycling with 1.0 of C/R)

Long-lived FPs

Harmonize to environment
(No high-level wastes)

SCNES Mass Flow (per 300MWe)



300 MWe

Energy

System Boundary

Fast reactor without blanket

5.2 tHM/y

4.9 tHM/y

0.07 t/y

Non-nuclear utilization

Non-blanket inspection

Valuable FP recovery

0.3 tHM/y

Uranium

Fabrication

Metal fuel pyro-process

One thousand-yr disposal for decay

0.22 t/y

Stable elements (natural Uranium level)

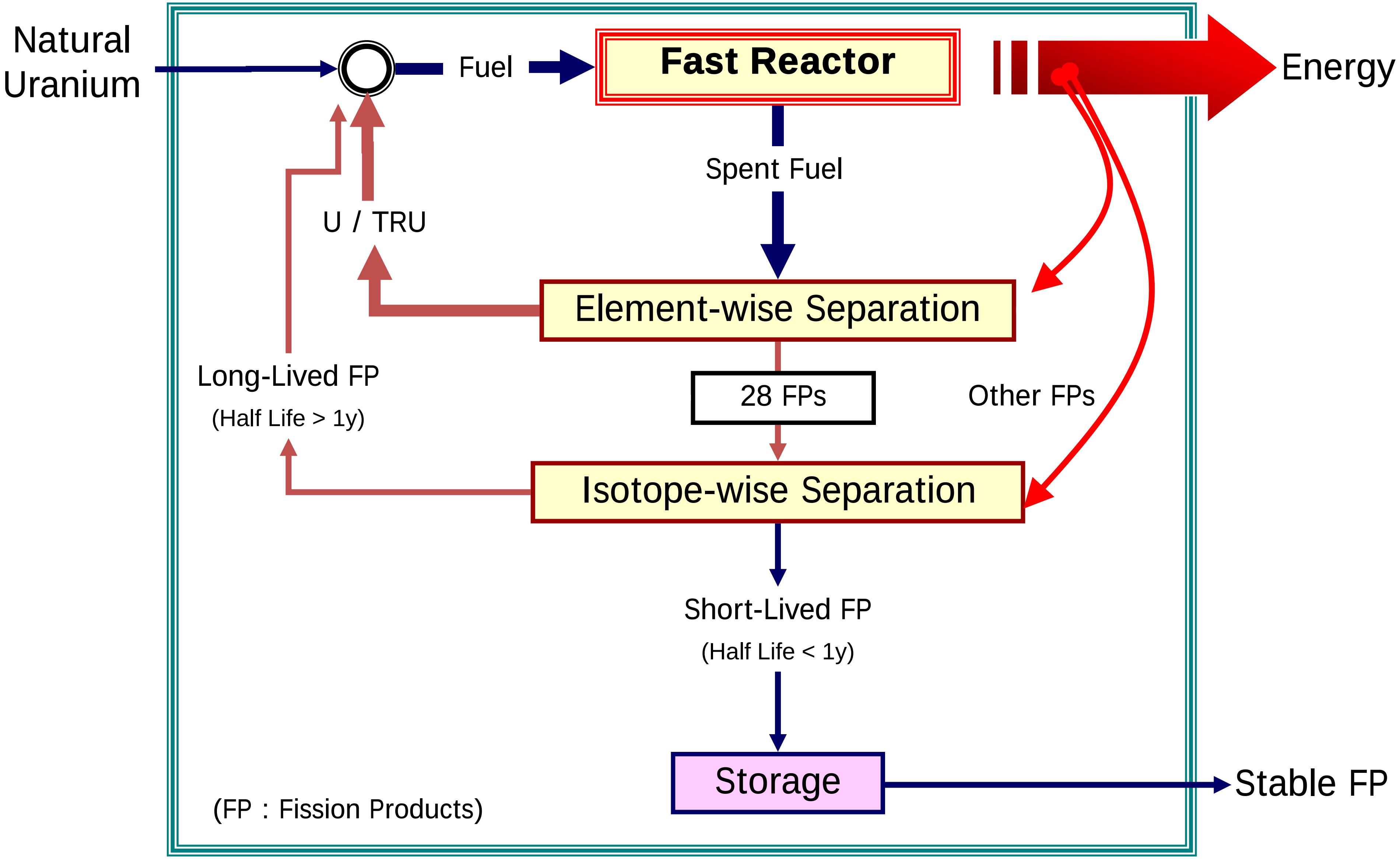
Actinides

4.9 tHM/y

FPs

2.7 tHM/y（isotope separation : 0.08 t/y)

Future Nuclear Energy System SCNES



Natural Uranium

Fuel

Fast Reactor

Energy

Spent Fuel

U / TRU

Element-wise Separation

Long-Lived FP

(Half Life > 1y)

28 FPs

Other FPs

Isotope-wise Separation

Short-Lived FP

(Half Life < 1y)

Storage

Stable FP

(FP : Fission Products)

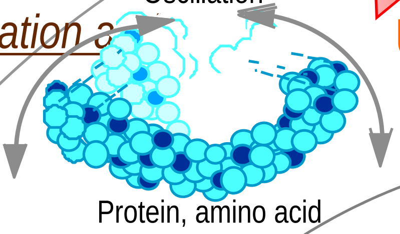
7. To learn and to assimilate the Nature for future nuclear civilization

- 1.To learn and assimilate the nature
- 2.Many items applicable to nuclear science and technology
- 3.Time spans：decade, century and millennium for nuclear civilization
- 4.Whole aspects of nuclear science and technology

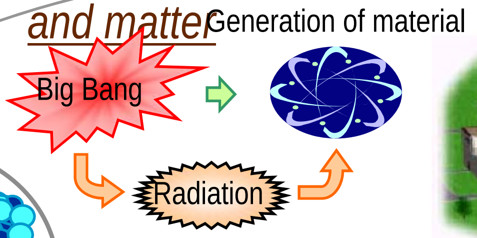
Future of Nuclear Science and Technology

New frontiers

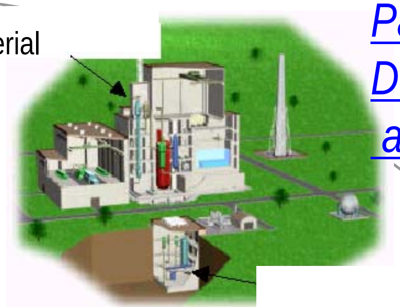
Life science
Molecular oscillation research Clarification of functions
Effects of radiation a
others



Study of the ultimate nature of the universe and matter

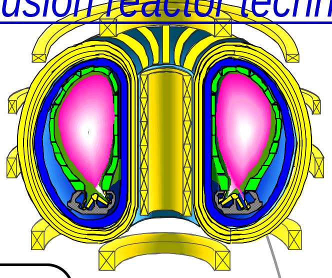


Sustainable Development

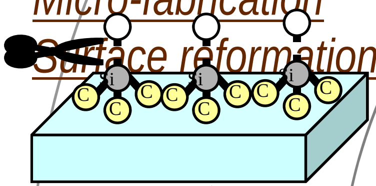


Passive safety system
Development of heat application technology

Combustion plasma in nuclear reactor
Fusion reactor technolo



Material creation and processing
New functional materials
Micro-fabrication
Surface reformation and others

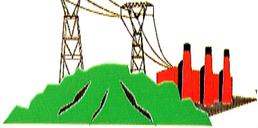


Use of radiation

- Physics
- Life science
  - Analysis of crystal structure
- Materials science
  - Research on material properties

Nuclear fission energy

Power generation



Nuclear fusion

- Core plasma research
- Development of reactor engineering elements

High power and high energy technologies

Accelerator and Laser

Reactor engineering and research reactors

Development of sophisticated, innovative technologies

Nuclear Science and Tech observed in the Framework of different Time Spans and Utilization

Decades, Centuries and Millennia on Nuclear Utilization

"Millennia" considering Progress of Civilization ,Half-Life of Radioactivity

Separation and Transmutation

Radioactive waste treatment

"Centuries"considering Commercialization of Nuclear Science and Technology

Accelerator

Fast Reactor Cycle

Nucl;ear Fusion

"Decades" considering Politics and Economics

Energy

Industry, Agriculture

Medical Use

s
Nuclear Fusion in the Sun

The Origin of Solar Energy

Over Million Years
Half-life of MA,LLFP

24000yrs
Half-life of Plutonium 239

1600yrs
Half-life of Radium 226

40～60yras
Design Life of Irradiated Material

30yrs
Half-life of Cesium 137

1／10000000000000秒
Time of Nuclear Reaction

Time Scale on Nuclear Process
(Knowledge of Mankind)

2billion yrs
Natural Fissoin
Reactor in Oklo

Heiann Era
1300Yrs ago

Great Wall
2200yrsago

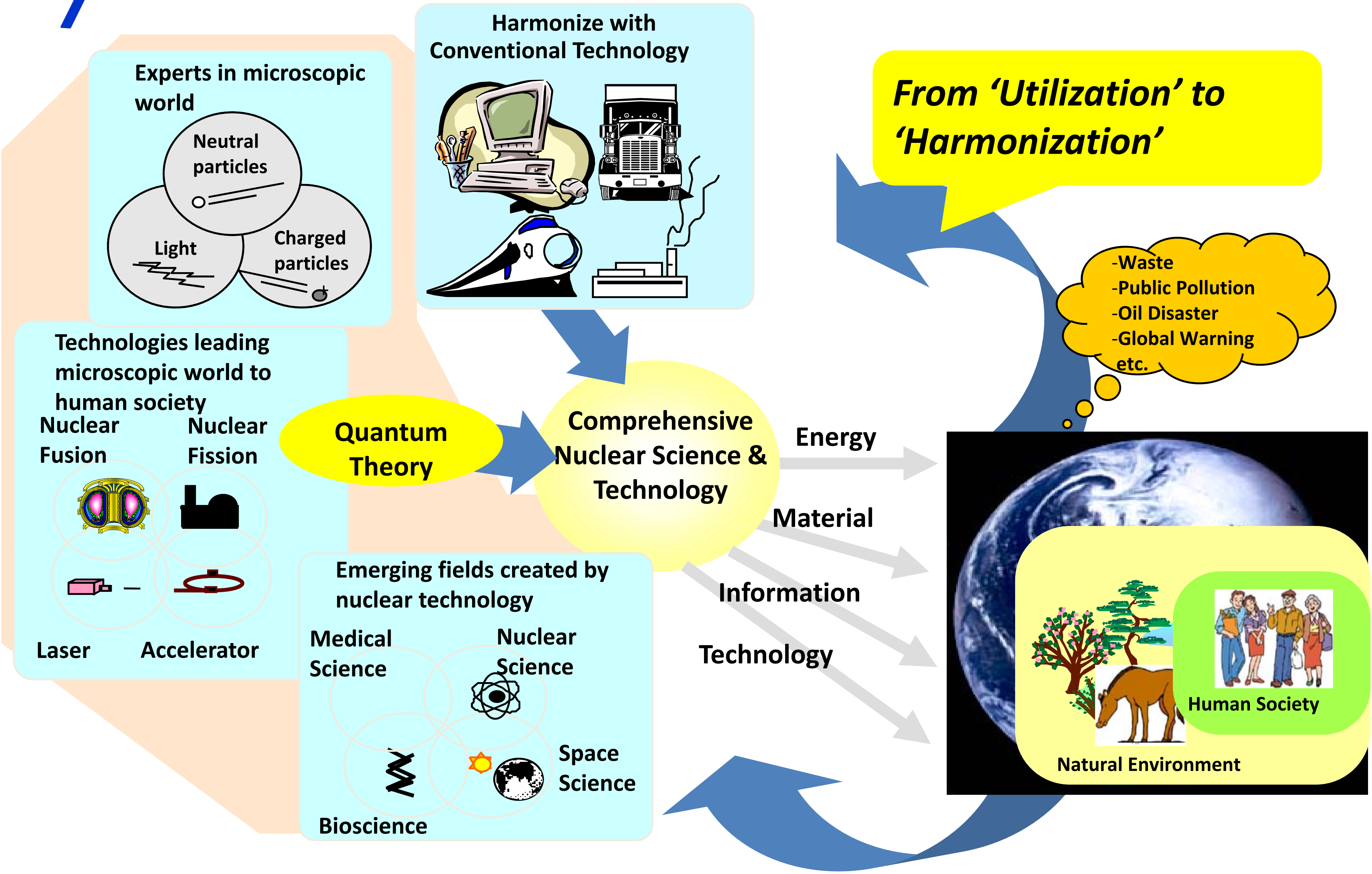
～200yrs
Industrial
Revolution

400～yrs
Renaissance

50～yrs
Computer, Nuclear Technology

Time Span on the History
(Memory of Facts)

Whole Aspects of Nuclear Energy Science and Technology



Experts in microscopic world

Neutral particles

Light

Charged particles

Harmonize with Conventional Technology

From 'Utilization' to 'Harmonization'

Technologies leading microscopic world to human society

Nuclear Fusion

Nuclear Fission

Laser

Accelerator

Quantum Theory

Comprehensive Nuclear Science & Technology

Energy

Material

Information

Technology

- -Waste
- -Public Pollution
- -Oil Disaster
- -Global Warning
- etc.

Emerging fields created by nuclear technology

Medical Science

Nuclear Science

Bioscience

Space Science

Human Society

Natural Environment

Neutron Balance in SCNES with Proliferation Resistance
-Pu Grade Target: Reactor Grade Pu-

Neutron Reactions	Core Fuel		Requirement
	MOX	Metal	
1. For Chain Reaction	**1.00**	**1.00**	**N_{fis1}+N_{fis2} =1.0**
Pu Fissile Fission (N_{fis1})	0.80	0.72	
Others Fission (N_{fis2})	0.20	0.28	
2. For Fuel Production (Pu Fissile Production)	**0.98**	**0.83**	Breeding Ratio =
^{238}U, ^{238}Pu, ^{240}Pu, capture (N_b)	0.98	0.83	(N_b+N_{p2})/(N_{fis1}+N_{p1}) ≧1.0
3. For Pu Protection (Taget: Rea. Grade Pu, (Np))	**0.24**	**0.16**	(N_p)/N_b≧0.18
Pu Fisslie,^{239},^{241}Pu, capture (N_{p1})	0.20	0.13	≧Reactor Grade Pu
^{237}Np, ^{241}Am Capture (N_{p2})	0.02	0.02	or N_{SFN} [n/s/kgPu]
^{243}Am Capture (N_{p3})	0.02	0.01	≧Reactor Grade Pu
4. For LLFP Transmutation	**0.24**	**0.24**	$T_{1/2}$ > 1 year FP Transmutation
LLFP capture (N_{fp})	0.24	0.24	with isotope separation
5. Others	**0.21**	**0.17**	
Total	**2.69**	**2.42**	
Generated Neutron by Fission	**2.90**	**2.90**	

1) Fundamental Data are delived from "Yoichi Fujiie', Masao Suzuki, "Nuclear Energy System for a Sustainable Development Perspective -Self-Consistent Nuclear Energy System-," Progress in Nuclear Energy, Vol. 40, No. 3-4, pp. 265-283, 2002" Re-composed by H. Sagara

2) MA composition data at equilibrium state are delived from "A. Mizutani, A. Shono and M. Ishikawa, "Investigation of Equilibrium Core by Recycling MA and LLFP in Fast Reactor Cycle(I)," JNC TN9400 99-043 (1999)

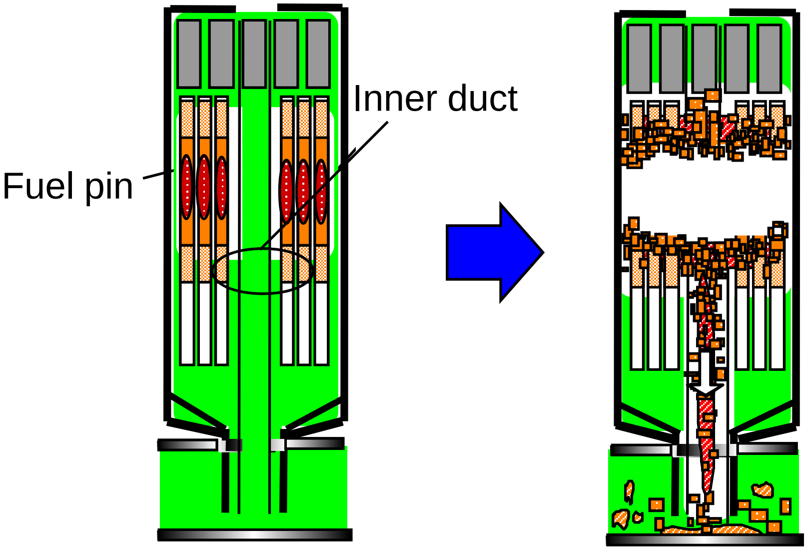
Objective and outline of EAGLE-project

Objective:

Confirm that the “re-criticality issue” would be eliminated from the CDA scenario by the early fuel-discharge from the core region, with clarifying the necessary design conditions for the re-criticality free core.

Approach:

- Use IGR and Out-of-pile apparatus of the NNC/Kazakhstan



Example of discharge-enhancing design and discharge phenomena

IGR (Impulse Graphite Reactor)

Table 1 Comparison of Energy Expansion, Resources for Power Generation and Delivered Wastes Volume

Power Station		Annual amount (ton)	
Type		Resources consumed	Waste generated
Thermal	Coal-fired	$2.2x10^6$	CO_2: $6x10^6$
			SO_X: $1.2x10^6$
			Ash:$5x10^4$
	Oil-fired	$1.4x10^6$	CO_2: $5x10^6$
			SO_X: $4x10^4$
Nuclear	LWR(Once-through)	Natural Uranium: 200(metal-equivalent)	30(Spent fuel)
	LWR		5(High-level vitrified)
	Pu-thermal	90(metal-equivalent)	5(High-level vitrified)
	FR	1(metal-equivalent)	5(High-level vitrified)

Note:when a power station with an electric generating power of 1 million kW is operated for a year.