

Nuclear Energy System for a Sustainable Development Perspective - Self-Consistent Nuclear Energy System-

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1. Introduction

1) Total Picture for Comprehensive Nuclear Science and Engineering

Civilization gives rise to science and engineering, and science and engineering support civilization; through the history of civilization, this inseparable relationship has been maintained. Science and engineering, however, should meet the requirements of civilization.

In developing science and engineering and introducing it to society, it is not easy to view the future by studying technological aspects alone. However, the ongoing dispute over nuclear science and engineering seems to be biased too much toward technological aspects. We live in an age where technology cannot always solve all of our problems. Social or economic benefits are important factors to consider; society will not choose anything that lacks economic benefits. This point should be kept in mind from the beginning, namely, from the development stage.

Although economic or social benefits are given a higher priority than technology, it is still difficult to view the future clearly. Scientific thinking that can develop into abstract or philosophical thinking will be more appropriate for viewing the future. At the turn of the century, scientific thinking should be developed to view the total picture of comprehensive nuclear science and engineering and its long-term perspective. This is the approach that society should support in determining the future direction of nuclear science and engineering as we head into the 21st century.

Nuclear science and engineering deal with the quantum world that has been studied since the end of the nineteenth century. It basically deals with a broad area of science and engineering related to light, charged particles, and neutral particles. Particle accelerators, lasers, nuclear fission reactors and nuclear fusion reactors in future are

devices designed to bring quantum-world to society. Nuclear science and engineering have so far focused on the use of nuclear energy as an energy source, and specifically nuclear power generation using light-water reactors. In the non-energy area, various radiation applications have been developed. While looking at civilization as a whole, the scope of those applications should be broadened in terms of comprehensive nuclear science and engineering.

2) Long-term perspective backed by a deep insight into 21st-century civilization

What civilization demanded for science and engineering was, in the ancient age, represented by natural energy such as sunshine, water flow, wind, etc, elements of food, shelter and clothing as material, language for communication as information and tools in living as technology and has increased in both quality and quantity along with the progress of civilization. Those demands have been basically four things: energy, material, information and technology. This will basically remain the same in the future. However, people understand that science and engineering has not been always obedient to civilization nor has done it guarantee the people a decent way of life. Energy-dependent civilizations that came into full bloom during the Industrial Revolution continued developing on the principle that the utilization of resources should be maximized. These civilizations were a prelude to the modern civilization characterized by mass-production, mass-consumption, and mass-disposal. Our civilization is now faced with environmental pollution, global warming and other environmental problems. We are at our turning point.

It is an undeniable fact that science and engineering has been used for military purposes throughout the history of mankind, and nuclear science and engineering is not an exception. It is important to know that there are both positive and negative aspects. To construct a new nuclear civilization, the concept that harmony should take precedence over utilization must be understood and confirmed. Fears and adverse reactions that people display with regard to the enormity and the great level of energy density of nuclear energy must be readily acknowledged. It is important to construct a nuclear science and engineering system that can be accepted and supported by society.

Limited resources and limited capacity on the part of the environment indicate that we must depart from a civilization of mass-consumption and mass-disposal and that we must approach to a recycling based society. Is mankind wise enough to make a shift to a recycling based society in the next century?

Although expectations abound that nuclear science and engineering can play a key role in approaching to this recycling based society, the possibilities of nuclear science and engineering and what follows from its fundamental characteristics must be considered.

It is worth while to note that there seem to be three kinds of spans for the consideration of nuclear science and engineering: a span of decades from political and economic viewpoints, a span of centuries for the research and development of monumental science and engineering to practical use such as fast reactors and fusion reactors, and a span of millennia for the continuation of civilization and the half-life of radioactivity. Therefore, significant factors to discuss are obtaining a clear perspective of the roles these spans play, clarifying realistic goals to reach with a long-term perspective that includes social concerns, and working to reach these goals. We also need to deal with the purposes flexibly and prepare for technological alternatives to solve technological issues.

3) Balanced coexistence of idealism and realism in nuclear policies

Although nuclear science and engineering has developed and gained a significant foothold in society during the century since quantum world was inducted as a subject of scientific research and development, it is appropriate to think that this nuclear science and engineering is still in its development stage, indicating that further research and development are needed. Nuclear science and engineering draw keen interest and expectations in the future whereas some forms of nuclear technology are practical and used in social, economic, and political frameworks. As we know from history, it sometimes takes more than a century for a new science and engineering to be understood and become familiar to the people in general. In introducing nuclear science and engineering to society, therefore, both leadership and accountability are needed.

In formulating nuclear policies that can contribute to the construction of well balanced nuclear science and engineering, the coexistence of the idealism that transcends the times and the realism that seeks solutions to problems should be encouraged. The formulation of realistic policies through clarification of future perspective is important. Nuclear fuel cycle policies must be based on this approach.

Economic benefits available or technological achievements made this moment cannot

be ignored when formulating actual policies. Although these two points are important factors, it is not clever, however, to determine actual policies without clarifying future prospects. Here, the balanced coexistence of idealism and realism must rise to meet the future.

Hereafter we will confine arguments on the perspective for nuclear energy development based upon the discussion above.

4) Why we propose a self-consistent nuclear energy system

We should all recognize the fact that a great part of populations in developing countries still live in such a condition that they cannot benefit from the usefulness of electricity enough. According to an estimate, the world energy consumption and the consumption of electricity in the year 2050 would become 2.5 and 3 times as large as that of the year 2000. The world energy consumption in the year 2100 would become 4 times as large, and the electricity consumption in particular would become 5 times as large (J.Holdren , 2000, Ref.1).

We are convinced that nuclear energy continues to be one of essential energy sources in the long future. We should be confident and proud of nuclear technology and actively promote research and development aiming at the construction of nuclear era in the 21st century. However, many of our colleagues and fellow workers have a somewhat cloudy outlook for the future of nuclear energy, and feel the stagnant situation in spite of the glorious and brightening history and achievement in light water reactor development.

It is our understanding that such a cloudy outlook is attributable to the following concerns:

- Significant delays in the development of fast reactors and related nuclear fuel cycle, which was drawn in the 1960's.
- Difficulties in the development of “ heavy and huge ” technologies, such as nuclear technology, under the present market-driven economy and the free-enterprise system.
- Difficulties in the competitiveness of nuclear energy against advanced fossil energy in power generation costs, and against co-generation and dispersion system.

In order to break through the circumstances mentioned above, it is necessary to go back to the starting point of nuclear technology development to recognize potential abilities of nuclear energy, reconsider what nuclear energy should be, and clarify the vision that to be aimed at.

Taking into account the circumstances mentioned above, a “Self-Consistent Nuclear Energy System (SCNES)” has been proposed by Dr. Fujiie.(. Fujiie , 1993, Ref.2)

It is possible to achieve, we consider, a breakthrough to reactivate nuclear energy development by establishing a vision that is based on the inherent and essential nature of nuclear energy for the future development. We view the SCNES as a ultimate scientific goal with which the development scenario and concept for R&D are discussed.

This paper presents the results of the arguments of the scientific feasibility of SCNES performed based on the latest information. In addition, long term and near term goals for the element technology development are also presented.

Lastly, the relationship between the SCNES and ongoing R&D activities for the future goals of nuclear energy systems like those in the frame of the Generation IV nuclear energy system (GEN-IV) is discussed.

2. Scientific Feasibility of SCNES

1) What is SCNES?

The SCNES is defined as a system which satisfies simultaneously the following four objectives at least.

Objectives of the SCNES;

1. Energy Production
2. Fuel Generation
3. Environment protection
4. Safety assurance

Figure 1 illustrates the concept of SCNES.

SCNES has the ultimate goal of full utilization of nuclear resources and “zero-release” of radioactive waste by recycling fuel and radioactive material, and “ zero-release of radioactive material” by assuring plant safety.

“Zero-release of waste” seems to have a potential to be realized in nuclear energy system comparison with fossil energy system. Never the less, we believe further reduction of radioactive waste is inevitable for nuclear energy development responding to the desire of general public.

2) Scientific Feasibility Evaluation

“ Scientific feasibility” here means whether it is feasible for SCNES to be materialized in principle and idealistic condition. The feasibility can be demonstrated by providing the following. First, the ultimate goal can be achieved within the range of

the neutrons and energy generated by nuclear fission. Assets of a fission reaction are emerging neutron of about three in number and released energy of about 200Mev. Secondly, the required inventory (equilibrium inventory) of fission products for incineration in the reactor core can be within the range to be loadable in the blanket and around the core. That is, as described below, the feasibility can be evaluated by the balances of neutron, energy and mass.

(1) Neutron balance

Fission neutrons \geq (Neutrons for chain reaction + Fuel breeding + Radioactive FP incineration)

(2) Energy balance

Attainable energy \gg Required energy for recycling

(3) Mass balance

Equilibrium inventory of FPs in a reactor \leq Loadable inventory around the core

The feasibility of these points has been investigated by a research team in Research Laboratory for Nuclear Reactors at the Tokyo Institute of Technology, to conclude that feasibility is evident (A. Shimizu, 1994, Ref.3). The Institute of Applied Energy has been studying engineering concepts for SCNES. (M. Mayumi, 1999, Ref.4) The following outlines the results of our feasibility evaluation for the SCNES with fast reactors based on recent information (nuclear cross section and other data).

3)Features of fast reactors

Fast reactors have the following well known features:

- Parasitic capture of fuel is low and fuel breeding is feasible.
- Transuranic elements (TRUs) other than Pu, such as Np, Am, and Cm (so-called minor actinides; MA), existing in the spent fuel can be utilized as fuel.
- By varying the depleted uranium inventory in the blanket around the core, not only fuel generation, but also incineration of transuranic elements (TRUs) can be achieved with a core structure within the same plant.

In fast reactors having these features, the burning (incineration) of transuranic elements can be achieved by actinide recycling that utilizes transuranic elements other than Pu for recycling together with Pu. Consequently, the crucial issue in the SCNES feasibility evaluation is whether the system ensures FP incineration while maintaining fuel generation (fuel self-sustaining) capability and contains radioactive fission products in the system.

From this viewpoint, we have evaluated the feasibility for a typical oxide fuel and

metallic fuel fast reactor core.

4) Neutron balance

In an oxide fuel reactor core, 2.9 neutrons are generated per nuclear fission. Among these, 1 neutron is consumed to sustain the chain reaction and another 1 in fuel generation. Considering that 0.45 neutrons are consumed in parasitic capture by fuel and other parasitic absorption, the remaining 0.45 neutrons would be available for the incineration of radioactive FPs produced by the fission. On the other hand, in the case where all the radioactive fission products having a half-life of one year or more are recovered from the spent fuel at 100% recovery rate, processed through isotope separations, placed in the reactor, and then incinerated by neutron irradiation, the number of required neutrons for FP incineration would be 0.24 per fission, which is less than the available neutron number of 0.45. Thus, neutron balance can be achieved. (Table 1)

There are nine FPs, that are I, Tc, Cs, Pd, Zr, Sn, Se, Sr, and Sm, to be incinerated or to be required for long time storage for decay.

In the case of a metallic fuel core, since the neutron absorption by parasitic capture is low, the available neutrons for FP incineration are 0.72. Thus a neutron balance is ensured with sufficient excess neutrons.

However, in the case when isotope separations are not available, the number of neutrons needed for incineration of radioactive FP are greater than 1, so a neutron balance can not be achieved even in a metallic fuel core. Isotope separation technologies for FPs are inevitably necessary to achieve the ultimate goal of SCNES using fast reactors.

5) Energy balance

In nuclear fuel recycling facilities, reprocessing and fuel fabrication processes are considered to be the largest energy consumer. Even when isotope separation of FPs is assumed, the required process energy is 1.9% of that obtained by nuclear fission. Consequently, energy balance can be achieved .

6) Mass balance

The equilibrium inventory that is necessary to make the amount of FPs incineration quantitatively balance with the radioactive FPs generated by fission, reaches an approximate total of 14 tons in a 1 GWe fast reactor. Compared to the case of a conventional 1 GWe fast reactor, in which approximately 40 tons of blanket fuel are

installed around the core, the above-mentioned 14 tons of FPs are an amount that can be loaded around the core. That is, mass balance for the radioactive fission products can be achieved .

7) Summary of scientific feasibility

From the above results, SCNES is evaluated to be feasible scientifically. The key word “scientific” is used here since the evaluation is conducted assuming ideal conditions. For example, it is assumed that fission products to be incinerated can be fully recovered, complete isotope separation can be achieved, and only necessary fission products can be selected to be loaded in the reactor. The scientific feasibility does not necessarily mean the engineering feasibility. However, the scientific feasibility is a key to research on the engineering materialization of the SCNES concept and it is one of the factors that encourage us for further research.

3. System Concepts for SCNES

1) Element technology for long term goal

we can draw a system concept for SCNES that is composed of the following element technologies and subsystems achieving the ultimate goal. (Fig.2):

Element technologies and subsystems for SCNES;

Actinide recycling system with fast reactors

Radioactive FP elements recovery

Isotope separation system for FP elements

System that incinerates long half-life FP isotopes in the fast reactor core

Storage system for short life FP elements for decay

It is possible to introduce an accelerator driven systems to help and ease the balances, but discussion made here does not include ADS system for simplicity .

2) Major development items

Establishment of actinide recycling system with fast reactors is the key technical issue and isotope separation technologies for FPs are inevitably necessary to achieve the ultimate goal of SCNES using fast reactors.

In the evaluation for neutron balance, the TRUs and radioactive FPs (30 nuclides) in spent fuel assumed to be recovered at 100% recovery rate. If innovative technologies can be developed that ensure a high recovery rates (6 nines) for the elements recovery and isotope separation processes, the incineration capability of the nuclear reactor core is sufficient, and the radioactivity in high level waste could be reduced to the level of

natural uranium.

The innovative technologies, which ensure high-efficiency recovery or isotope separation at a rate of 6 nines or more are one of major development items, but they cannot be illustrated in detail from the engineering point of view at present. Although isotope separation technologies, such as Atomic Vapor Laser Isotopic Separation, are now being studied in advanced uranium enrichment technology.

Regarding the elemental separation/recovery technologies, we should not adhere to the development of the technologies, such as PUREX, which pursue recovery of clean Pu alone. Instead, it is necessary to develop a reasonable separation/recovery technology that can be compatible with the capability of impurity acceptance in the reactor.

In order to improve the incineration efficiency of FPs, and to mitigate the purity requirements for recovered FPs, further innovative technologies may be required, such as high-neutron flux FP incineration reactors, and accelerator-driven reactors.

3) Near-Term Goals

Why we need near-term goals

The innovative technologies that will make it possible to implement high-efficiency recovery or isotope separation with 6 nines or more of efficiency cannot be identified at present stage. Accordingly, investigation of near-term development scenarios requires the setting of near term goals.

Viewpoint for near-term goal setting

We discussed the near-term goals by adopting the following requirements:

- Scenarios can be drafted for development and technology selection toward goal achievement. (The feasibility of achievement can be forecast relatively easily.)
- Significant effects can be expected from incineration.
- Nuclear fuel recycling technology that does not place special importance on Pu can be achieved.

In order to select the fission products to be incinerated in the near-term goals, the evaluation from the above-mentioned viewpoints has been conducted for key FPs. As a result, we have selected I, Tc and Cs. The following near-term goals are set up.

Near-term goals

Actinide recycling by fast reactor (recovery rate; 3 to 4 nines)

Recovery of I, Tc, Cs and Sr (recovery rate; 2 to 3 nines)

Incineration of I, Tc, Cs by fast reactor

Storage of Sr for decay

4) Feasibility of achieving near-term goals

In order to confirm the feasibility the FP incineration in the near-term goals we evaluated their neutron and mass balances. .

We have assumed that the target FPs for incineration are in a chemical form for loading that is considered appropriate under current stage and that they would not be treated in the isotope separation process. We evaluated them in terms of the required number of neutrons including the amount for parasitic capture as compounds and the equilibrium inventory. The number of required neutrons is 0.32 and the equilibrium mass is 12.4 tons. Thus, both neutron balance and mass balance are found to be achievable.

Further, an evaluation of specific recovery processes has revealed that in the improved PUREX process, dry oxide process, and dry metallic process, the target recovery rate could be achieved by adding processes or modifying the processes.

5) SCNES to meet the near-term goals

A system concept for SCNES that meets the near term goals is shown in Fig.3. The near term SCNES will reduce high-level waste radioactivity and potential toxicity (1/100 to 1/1000 of one-through level as shown in Fig. 4).

The SCNES realizes an actinide recycling system that does not regard Pu as a special substance, which is a desirable system in the view of nuclear nonproliferation

6) The relation between the reduction of the radioactive materials and the geological disposal

Achievement of reduction in high-level waste radioactivity and amount of heat generation does not rule out the necessity of geological disposal of high-level waste. Instead, it will reduce the burden of geological disposal and thus promote public acceptance of geological disposal, leading to improved public acceptance of nuclear energy itself. Therefore, it should be noted that SCNES and geological disposal can complement each other.

4. Global Goals of Nuclear Energy and prospects for international collaboration

4.1 Discussion on GEN-IV goals

Figure 5 shows the goals of GEN-IV comparing with SCNES.

During the discussions about the goals of GEN-IV in the expert group meeting held in Korea in August 2000, “sustainability” was proposed for an additional goal. As a result, GEN-IV and SCNES have the common and consistent concept of goals. The goal of “sustainability” is deeply-rooted in the inherent nature of nuclear energy and is essential as a long-term goal.

There are opinions in the US technical experts that further reduction of radio-waste is unnecessary. Nevertheless, if we consider the span of millennium with the half-life of radioactivity further reduction of radioactivity of nuclear waste lies on the way to the goal. It is recommended for nuclear energy development responding to the desire of human race, because the further reduction of radioactivity is achievable based on the intrinsic nature of nuclear energy.

The discussions on economics and nuclear proliferation resistance aspects, which are not written in SCNES goals explicitly, are shown below.

1) Economic competitiveness

It is important to pursue economic efficiency and competitiveness. It would be necessary to consider how the term "economic efficiency" be defined. That is how to measure the economic efficiency, and how external costs should be included in the comparison with other energy systems. It would be necessary to argue these items.

We should recognize that economic competitiveness is a primary goal but is not all.

2) Nuclear proliferation resistance

As for the SCNES concept we do not adhere to the technologies, such as PUREX, that intends to recover clean Pu alone. Instead, we believe it is necessary to develop a reasonable separation/recovery technology, which is compatible with the capability of impurity acceptance in the reactor. We have selected the actinide recycling process which does not give Pu special substance, taking into account both reduction of the radioactive waste and improvement of the intrinsic nuclear proliferation resistance.

Our fundamental ideas on nuclear proliferation resistance are follows.

a) We consider the prevention of nuclear proliferation as a step towards the ultimate extinction of nuclear weapons. The nuclear states should continue their efforts to reduce nuclear weapons.

b) Development of nuclear energy is essential in terms of getting rid of the motivation and intention of nuclear proliferation because nuclear energy can significantly ease the world energy supply issues, which would cause international conflicts as ever. Especially, the effective utilization of natural uranium and reduction of radioactive

waste through recycling, which is one of the advantages of nuclear energy, are the important themes in the future development of nuclear energy.

c) In the meantime, it goes without saying that the developments of reactors and the fuel cycle technologies with higher nuclear proliferation resistance are preferable in order to promote the global utilization of nuclear energy. SCNES which is going not to apply pure separation process as mentioned above can meet the requirements for non-proliferation.

d) However, while the evaluation methods and the criteria regarding the nuclear proliferation resistance have been discussed at the workshop on Technical Opportunities for Proliferation Resistance of Global Civilian Nuclear Power Systems (TOPS, Ref. 6), at present, it will take still some more time to obtain international consensus on these matters. Therefore, we should avoid the statement that the measures to improve the nuclear proliferation resistance that might damage strongly the economic efficiency and other essential advantages inherent to nuclear energy, must be prepared as the absolute conditions of the nuclear development and employment. It is our understanding that the issues on the nuclear proliferation resistance technology is still at the stage of problem definition. So, considerations should be taken so that excessive pursuit of the nuclear proliferation resistance would not jeopardize potential abilities of nuclear energy.

4.2 Activity for “Zero release system”

1) TRU burning and FP transmutation

Table 2 shows research activities for TRU burning and LLFP nuclear transmutation in the world. SPIN (M. Viala, 1994, Ref.7) project in France and DOVITA (A. V. Bychkov, 1997, Ref. 8) project in Russia have been initiated for solving the radioactive waste issues, which are intrinsic to nuclear energy, by reducing the radioactivity contained in nuclear waste. Therefore, both studies are positioned on the half-way to the ultimate goal of SCNES (zero-release goal).

2) Elimination of re-criticality issues in fast reactors

Conservative safety design, which applies the ALARA (As Low As the Reasonably Achievable) principle to normal operation and the “ Defense in depth concept ” to accidents” has been incorporated and severe accident management measures utilizing the probabilistic safety assessment methodology have been promoted. These measures have been contributed to zero-release in practice.

However, in the fast reactor core, a large amount of molten fuel may be centralized during “Hypothetical Core Damage Accidents (HCDAs)”, which results in a re-criticality, leading to the generation of mechanical energy.

In order to materialize the zero-release concept, which does not require the emergency evacuation in a HCDA, in a reasonable design concept, it is important to eliminate the possibilities of re-criticality during HCDAs.

In this context, it is necessary to provide design features, which promote discharge of molten fuel outside the core before the centralization of molten fuel occurs in the early stage of CDA, and to verify the effectiveness of the design. As the design feature for the elimination of re-criticality, installation of a duct within the fuel assembly, which facilitates discharge of molten fuel before fuel melt extends to the adjacent fuel assemblies, is conceived. Such design feature can provide a simple countermeasure against re-criticality considering one-dimensional behavior. This concept can be demonstrated by in-core tests.

Japan and the Republic of Kazakhstan are now working on a collaborative research program in order to confirm the principle of re-criticality elimination, which is scheduled to be implemented from 1998 to 2004. Research activities are being carried out utilizing Inpile Graphite Reactor (IGR) test facilities and out-of-pile test facilities at Kazak’s NNC.(H. Endo, 2000, Ref.9)

3) EPR non-evacuation principle

The European Pressurized Reactor (EPR, (W. Frish, 1997, Ref. 10) concept also lies in the direction for zero release with applying non- evacuation principle in case of severe core damage.

4.3 Prospect for international collaboration

As explained above, consistent efforts have been made to achieve the zero-release concept.

In the recent discussions at the TOPS and GEN-IV international workshops, evaluations of the nuclear proliferation resistance for various fuel cycles, including the closed cycle, and the initiation of studies for the fuel cycles with enhanced nuclear proliferation resistance have been insistently recommended. GEN-IV has the common and consistent concept of goals with SCNES. Though GEN-IV would have shorter time span of interest.

As discussed above, future nuclear technologies should aim at recycling and zero-release. Steady progress has been made in the establishment of international

consensus on the future goals of nuclear energy development. Therefore, it can be expected that there would be a growing possibility of international collaboration.

5. Conclusion

The scientific feasibility of SCNES, whose ultimate goals are full utilization of nuclear energy resources and zero-release of radioactive material, is presented and its system concepts are illustrated.

SCNES is not just a dream. We view SCNES as a primary future target of development, although a great deal of R&D is required to realize its system concepts.

By comparing with recent GEN-IV goals, the basic directions for the future nuclear energy development are common and consistent. Therefore, a possibility of international collaboration is growing in magnitude.

In implementing long-term R&D like nuclear energy development, it is important to draw the ultimate goals and clarify the vision to aim. As communication with the public is a must issue in a democracy, it is time to present and show potential capabilities and future prospect of nuclear energy to obtain understanding and positive support of the public.

The principles and the visions of nuclear technology development should be further discussed.

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Table 1 Neutron Balance in SCNES

Items	MOX Fuel Core	Metal Fuel Core
Required Neutron		
1. For Chain Reaction :		
Fissile (n,fission)	0.80	0.72
Fertile (n,fission)	0.20	0.28
2. For Fuel Generation* ¹ : Fertile (n,capture)	1.00	0.85
3. For FP* ² Transmutation : FP Target (n,capture)	0.24	0.24
4. Others :		
Fissile (n,capture)	0.20	0.13
Caputure in Structural Material,Sodium etc.	0.25	0.20
Total	2.69	2.42
Generated Neutron by Fission	2.90	2.90
Available Neutron for FP Transmutation* ³	0.45	0.72

*1 Fuel Generation Ratio = 1.0

*2 with isotope separation

*3 (Available Neutron for FP Transmutation)

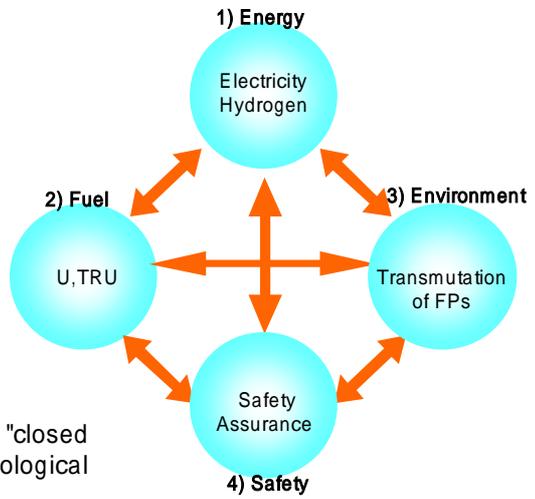
= (Generated Neutron) - [(Required Neutron) - (Neutron for FP Transmutation)]

Table 2 TRU burning and FP transmutation studies

	Organization	Project	Transmutation Device	Target Nuclides	TRU Recovery
USA	LANL	ATW	ADS	U TRU Tc I	
	ANL	IFR	Metal FR	MA	Electro-refining (Metallic Fuel)
France	CEA	CAPRA	FR	Pu	Solvent Extraction with DIAMIDE
		SPIN	FR ADS	MA Tc I Cs Sr	Solvent Extraction with DIAMIDE
EC	CEA EDF ECN FZK IAM ITU	EFTTRA	HFR	Tc I Am	
Switzerland	PSI		LWR ADS	Pu MA	
Russia	RIAR	DOVITA	FR	MA	Electrowinning (Oxide Fuel)
	IPPE		ADS	MA	
Japan	JAERI	OMEGA	ADS	MA Tc I Cs Sr	Solvent Extraction with DIDPA
	JNC		FR		Solvent Extraction with CMPO
	CRIEPI		Metal FR		Electro-refining (Metallic Fuel)

Criteria of Ultimate Nuclear Energy System

- 1) Energy : high efficiency, multi-purpose usage
- 2) Fuel : abundant enough resource to produce fuel for long-term energy supply
- 3) Environment : no production of RW by transmutation or containment
- 4) Safety



Learning from Nature

An ultimate nuclear energy system should be a "closed system" with materials similar to those in an ecological system.



- Full utilization of nuclear resources (Recycling)
- Transmutation and containment of RW (Zero-Release)

Figure 1 Self-Consistent Nuclear Energy System (SCNES)

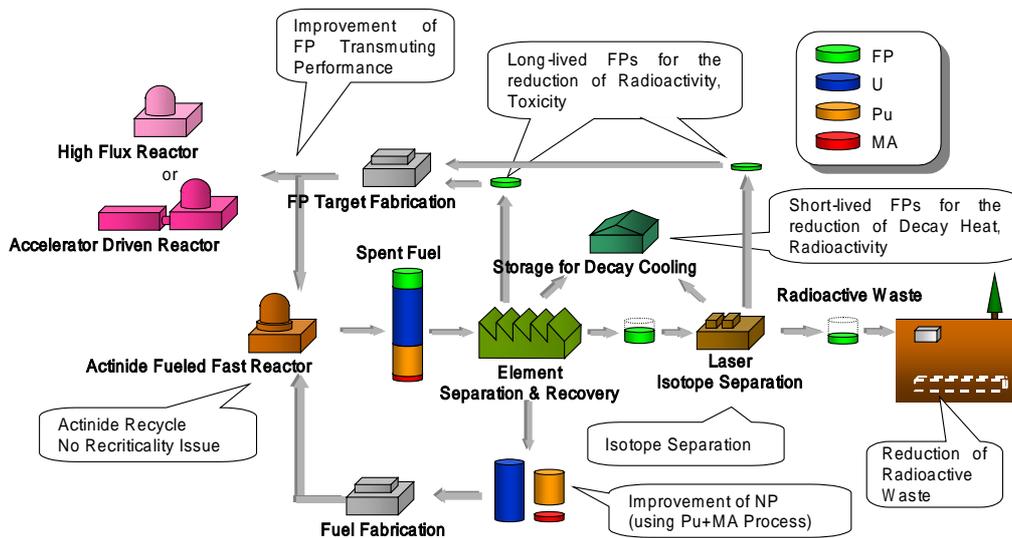


Figure 2 SCNES and Fuel Cycle (Long Term Goal)

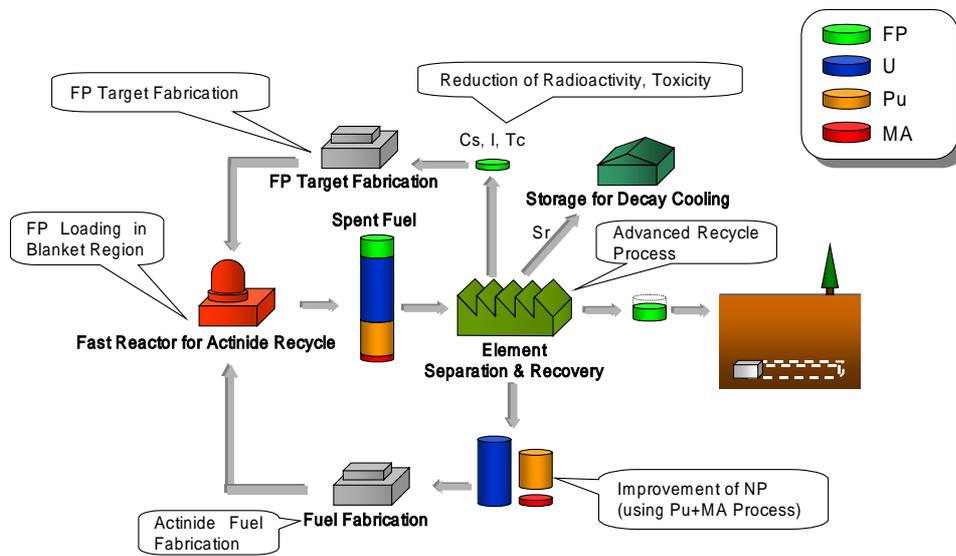


Figure 3 SCNES and Fuel Cycle (Near Term Goal)

Reduction of HLW by SCNES on near term goal

- Actinide :99.9% Recover for Recycling
 - I, Tc, Cs :99% Recover for Transmutation in Blanket
 - Sr :99% Recover for Cooling
- Relative to once-through core

Item	50yrs later	1000yrs later
Radioactivity	1 / 40	1 / 90
Radioactive Toxicity	1 / 500	1 / 300
Decay Heat	1 / 140	1 / 300

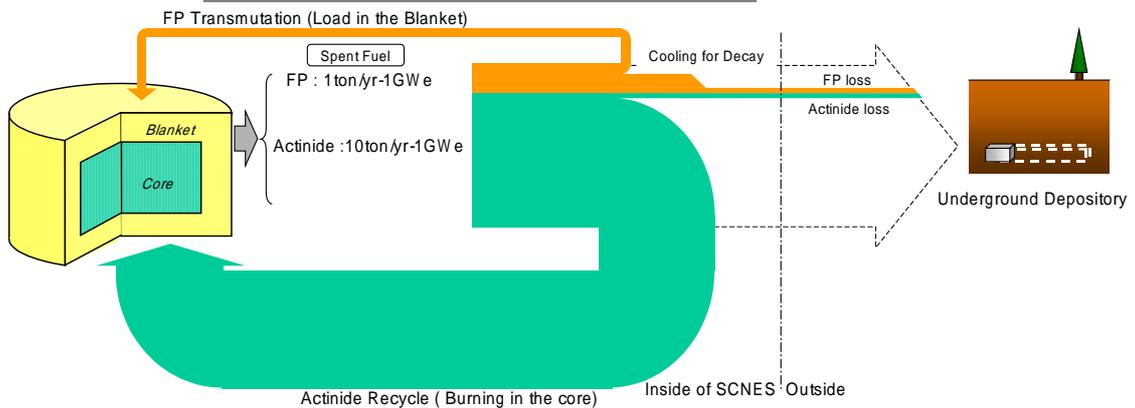


Figure 4 Reduction of Radioactivity and Toxicity

SCNES Goals

<u>Energy</u> --High efficiency, Multi-purpose usage
<u>Fuel</u> --Abundant enough resource to produce fuel for long-term energy supply
<u>Environment</u> --Non production of radioactive waste by transmutation or containment
<u>Safety</u> --Passive safety and re-criticality free core concept

Generation IV Goals (United States)

<u>Economics</u> --Competitiveness to cost from other sources --Acceptable risk to capital with respect to other energy development
<u>Sustainability(*1)</u> -- Advanced sustainable options High uranium utilization Flexible use of fissile and fertile resources Waste minimization etc.
<u>Safety</u> --Extremely resistant to core damage accident --Demonstration of safety --Design afforded radiation protection
<u>Waste</u> --Complete technical solutions for all waste streams
<u>Proliferation Resistance</u> --The least attractive route for potential weapons proliferators

*1:under discussion in GEN-IV expert group

Figure 5 SCNES vs. GEN-IV goals