Die Vereinten Nationen haben 1992 „Grundsätze der nachhaltigen Entwicklung“ als Entschließung über die nachhaltige Entwicklung der Menschheit verabschiedet. Darin wird die Bewahrung des ökologischen Systems zur Erhaltung der Erde gefordert; gleichzeitig werden aber auch die ethische Frage der „Objektivität innerhalb einer Generation“, die Minderung absoluter Armut und die „Objektivität zwischen Generationen“ angesprochen, wobei vor allem „der nächsten Generation keine negative Hinterlassenschaft“ vermacht werden soll. Die Frage des richtigen Umgangs mit Abfällen ist von Natur aus eine Frage der Sicherheit und der Ressourcen, aber auch eine ethische Frage.

Die Erzeugung von Kernenergie dient eher dem Umweltschutz, wenn man den Vergleich zwischen radioaktiven Abfällen und Kohlendioxid in Betracht zieht. Die Erzeugung von Wasserstoff mittels Kernenergie ähnelt der ökologischen Beziehung zwischen der Sonne und der Erde; in beiden Fällen wird Kernenergie in chemische Energie umgewandelt.

Kernspaltung, Kernfusion, Teilchenbeschleunigung und Laser kommen samt und sonders auch im Universum vor. Eine Zukunft für die Kernenergie lässt sich finden, indem man von der Natur lernt und die Natur nachahmt.

Betrachtet man die Zukunft der Kernenergie unter dem Blickwinkel der Nachhaltigkeit, so ist zu erwarten, dass Energievorräte gesichert werden können und eine Umwelt geschützt werden kann durch ein Kernenergiesystem, das hoffentlich zu einer umfassenden Nuklearwissenschaft und -technik weiterentwickelt wird, die die Zivilisation an der Wurzel unterstützt.

Can Nuclear Energy Support Civilized Society in the 21st Century?

From a Civilization Based on Chemical Reactions to a Civilization Based on Nuclear Reactions

Yoichi Fuji-Ie, Tokyo, Japan

1. Sustainable Development for Mankind and Nuclear Energy

What does Sustainable Development for Mankind Mean?

To solve the paradox of the modern age, a shift in principles from use to harmony will be necessary. The moral values and social institutions required to construct a recycling-based society will of course be necessary, besides there should be measures for science and technology which enables the shift.

Mankind cannot discard the comfortable life it has achieved through the progress of science and technologies made up to the present. It is hard to believe that society will accept the seemingly masochistic requests of the defenders of the environment for a life ruled by nature and environment. The industrial revolution succeeded in converting a society ruled by the environment to a society ruled by energy in return for convenience and comfort, and was welcomed by the people.

If we hope to attain the “wholesome and cultured life” energy is needed, and resources must be secured. However, the oil-based civilization that made progress with mass production, consumption and disposal has reached a turning point, given that the discharge of carbon dioxide has created the problem of global warming. Only 200 years elapsed since the industrial revolution. As a result, environment conservation has become an issue equal to or greater in importance than the need to secure resources.

The United Nations passed and adopted “Principles of Sustainable Development” in

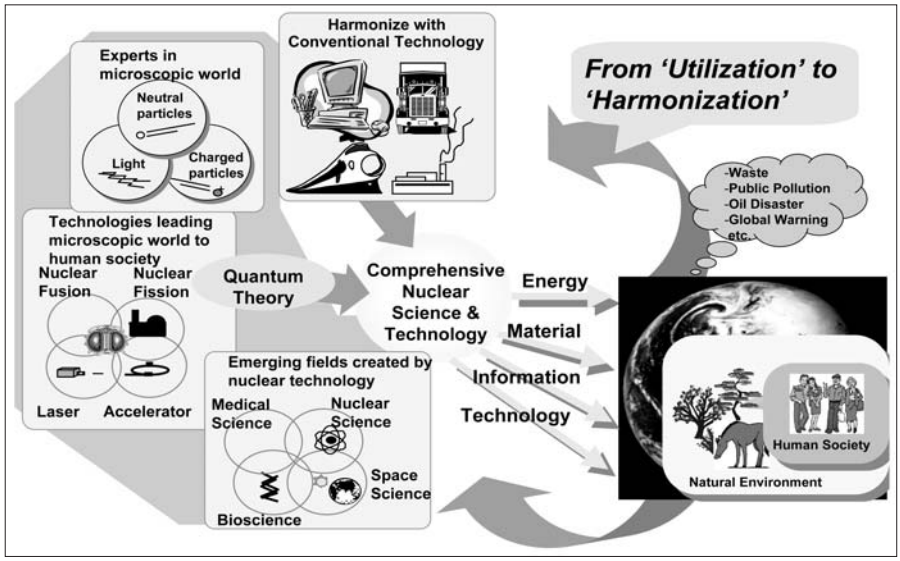

Fig. 1. What is required for the Nuclear Science and Technology in the 21st Century?

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1992, as a resolution on the sustainable development of mankind (see *Figure 1*). It advocates maintaining the ecological system to support the earth, while presenting the ethical issue of "impartiality within a generation," the reduction of absolute poverty and also "impartiality between generations," in particular "not leaving a negative legacy to the next generation." The issue of the appropriate handling of waste is by nature an issue of safety and resources, but is also an ethical issue. The issue of impartiality between generations should be considered, including the wasteful use of resources by the current generation.

Nevertheless, it is necessary to discuss the issues from the viewpoint of time (Is the period for continuing sustainable development 100 years or 1 million years?), space (the assessment of the limited area on the earth and capacity (Is the population to be taken care of 10 billion or 20 billion?). It is first necessary to consider time, space and capacity.

The period during which fossil energy can be depended upon is 200–300 years at the longest, based on the currently discovered volume of obtainable resources. If we are talking about a period of more than 1,000 years, the only subjects for consideration are using the energy created by the nuclear energy of the sun and received in the form of solar rays in the best way, both in terms of quality and quantity, or the nuclear energy generated on the earth. There are no ways left for mankind other than to reduce its population and return to the farming society of the past, or change its energy resources. Namely, this is

the shift from chemical energy to nuclear energy.

The disposal of radioactive waste is an issue that should be addressed with moral values. We should not be allowed to leave a "negative legacy" for future generations or the unacceptable results of the comfortable life enjoyed by the current generation. If you claim to have moral values, it is important not to increase the risk burden on future generations by reducing the duration of the risk of radioactive waste to the tolerance range of human civilization, which is less than a millennium far shorter than the age of the universe.

2. From a Civilization Based on Chemical Reactions to a Civilization Based on Nuclear Reactions

Combined Work of the Sun and the Earth

Can nuclear energy play a central role in the sustainable development of mankind in any way?

On the earth, as far as the five senses can recognize, only chemical reactions have taken place, with the exception of the existence of solar rays (*Figure 2*). It is necessary to start from the explanation that solar rays were essentially created by nuclear energy, and that the origin of universal energy is nuclear energy. It becomes significant how we can explain the links between nuclear energy and civilization as a whole.

If you take a moment to think, raising your eyes to the sky, you will wonder what the source of solar rays coming from the sun is, and when you realize that it is the nuclear fusion within the sun, you will, for the first time, notice the relationship between the earth and nuclear energy. Here, the sun will begin to change from something we worship to something we should study. As the result, you will realize that everything on earth takes place through the combined work of the sun and earth. The earth is open in terms of energy flow, seeking an energy source within the sun and returning the energy that it cannot use back into the space of the universe. Overwhelmingly large amounts of solar energy dominate the nature of the earth, transforming itself into phenomena such as wind, rain, and evaporation from the sea, which are seen favorably as renewable natural energies. The use of solar energy gives people a dream.

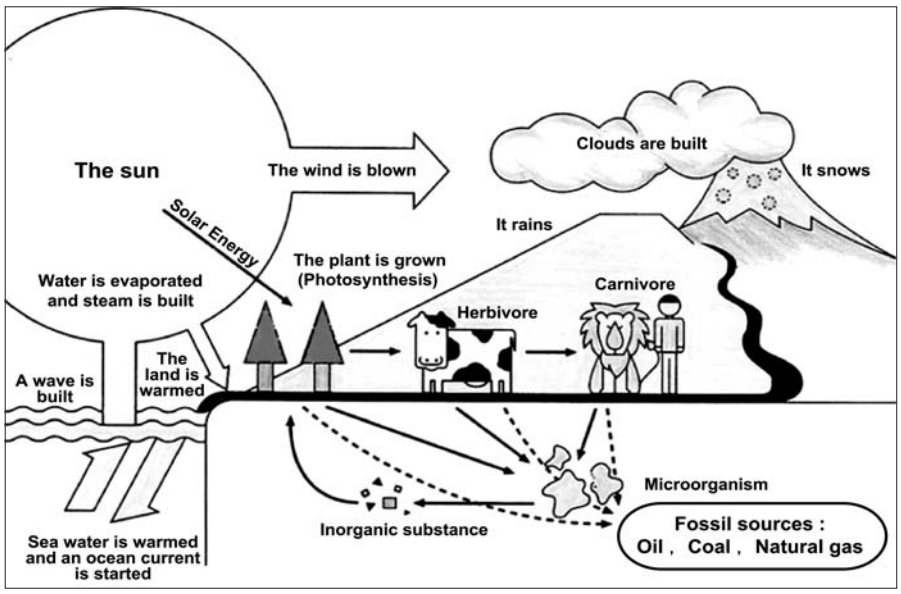

Fig. 2. Circulation of Solar Energy.

"You are my sunshine, my only sunshine. You make me happy. The sky is blue. You'll never know dear, how much I love you. Please don't take my sunshine away."

Certainly, the amount of solar energy reaching the earth is about 5E+03 Q (1 Q = 3E+14 kWh), 5,000 times as much as the amount of energy consumed by mankind at present, so it offers something very attractive. *George Gamow* put forward the theory that solar energy is created by a hydrogen fusion reaction, and taught us for the first time that the nuclear energy has influence on the nature of the earth. It was then made clear that natural nuclear fission reactor existed on the earth, and that the energy source of the universe was basically unleashed by nuclear reactions.

Ecological energy system

What we have to turn our eyes to on the earth is the existence of ecological system and its energy system. While the existence of ecological system is involved in the existence of mankind itself, solar energy is transformed to preservable chemical energy by photosynthesis, even though only at a level of 0.02%, to form a biosphere (*Figure 3*).

Securing resources and conserving the environment

Since the industrial revolution, comfortable lifestyles have been underpinned by a civilization based on fossil energy, born from the development of the steam engine, an artificial power, and the introduction of electric energy, which is easy to use. Mankind will not be able to discard the many contributions created by science and technology, including this convenience, easily.

However, the world created by this civilization based on fossil energy, which can also be called a civilization based on oil, is reaching a turning point as problems on the discharging side lead to global warming. Nuclear energy, either within the sun or on the earth, must be depended upon as an alternative, if the problems are to be handled within the capacity that the earth has.

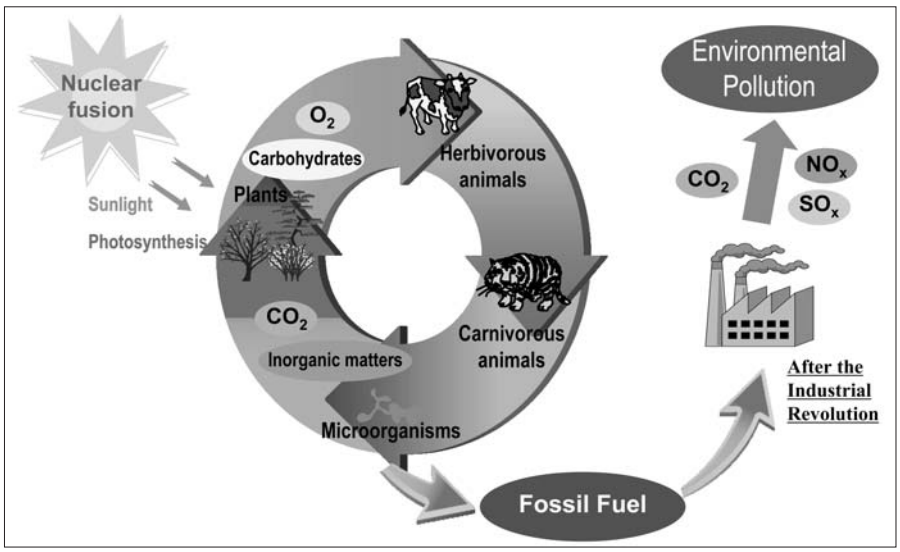

Fig. 3. Bounty from the Sun and Ecological System.

Waste is not necessarily generated from nuclear reactions alone. The products of chemical reactions include carbon dioxide, sulfur oxides and nitrogen oxides. The problems on the discharging side are not something particular to the use of energy; they include the problems of so-called industrial and domestic waste, such as used structures, equipment, parts and materials. How can we overcome the difficulty of making society aware of the comparison between types of waste?

It is important to compare the quantities of materials involved in the fossil energy system and the nuclear energy system. There is a difference as large as 1 million times between the energy created by chemical reaction and the energy of a nuclear reaction, and the latter has many advantages in supplying energy. One generates radioactive waste, the other industrial waste. If we considered carbon dioxide, which is not included in the category of industrial waste, the proposal of a carbon tax has not materialized. Materials such as used buildings, structures, parts, soil and concrete are industrial waste. Efforts are being made to reuse these. This is exactly what is meant by recycling.

People are beginning to look for a recycling-based civilization or a recycling-based society. As can be seen from the Recycling Law, limits have been set on the practice of using things and throwing them away. What is recyclable and renewable when we look at energy resources? Fossil energy is not recyclable, as it loses its resource value after a single combustion, generating waste. While efforts to prevent the generation of NO_x and SO_x have been made through a range of measures, the generation of carbon dioxide and water cannot be avoided, since they are the main materials generated by the chemical reaction. Fortunately, as water exists in abundance in the environment, it does not raise a problem. Carbon is a core element among organic substances and provided the basis for life to be born, and is an important element. The influence of carbon dioxide is determined by its concentration in the atmosphere, and the current situation, where its concentration is still continuing to increase, is certainly not acceptable. If it were eliminated, plants would not be able to grow, but if, on the other hand, there is too much of it, the heat balance of the earth will be adversely affected. (*Figure 4)*

A recycling-based civilization and a recycling-based society

If we are to hope for the sustainable development of mankind, while attaining targets of securing resources and conserving the environment at the same time, fossil energy has already reached its limit. It will be necessary to secure new energy sources that present better possibilities.

Our expectations will depend on solar energy or nuclear fission and nuclear fusion of the possibilities that the earth has. In either case, nuclear reactions will be depended upon, as the energy of the universe is nuclear energy. Depending on where the nuclear reaction takes place, within the sun or on the earth, the issue of disposing the material generated from the reaction, namely radioactive waste, may be raised. *(Figure 5)*

Nuclear power generation is more likely to conserve the environment, if the comparison between radioactive waste and carbon dioxide is considered. The creation of hydrogen by nuclear energy resembles the ecological relationship between the sun and the earth in that it consists of the conversion of nuclear energy into chemical energy. In principle, energy from hydrogen involves only a system of hydrogen and oxygen, and does not require the balance between substances to be considered. There is also sufficient water and oxygen in the atmosphere.

If we can create a hydrogen energy system with nuclear energy, a system similar to the ecological energy system in terms of conserving the environment can be constructed. I say similar, because the disposal of radioactive materials remains a problem.

3. The Basic Stance of Nuclear Development

Nuclear energy generation has grown into the principal electric power supply

An opposition to atomic bombs and a focus on peaceful use alone. This is the basic stance of Japan and the world in

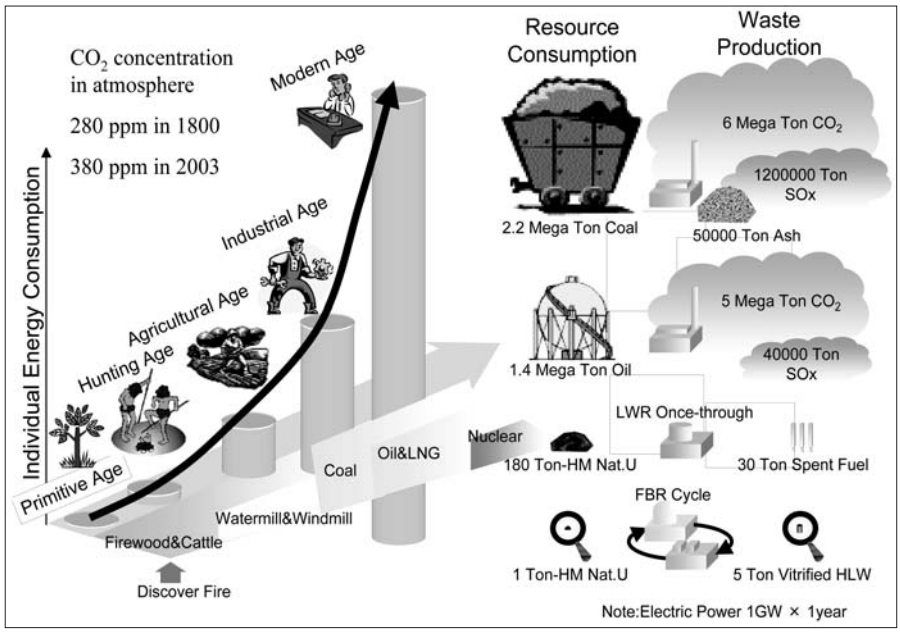

Fig. 4. From Control of the Environment to Control of the Energy.

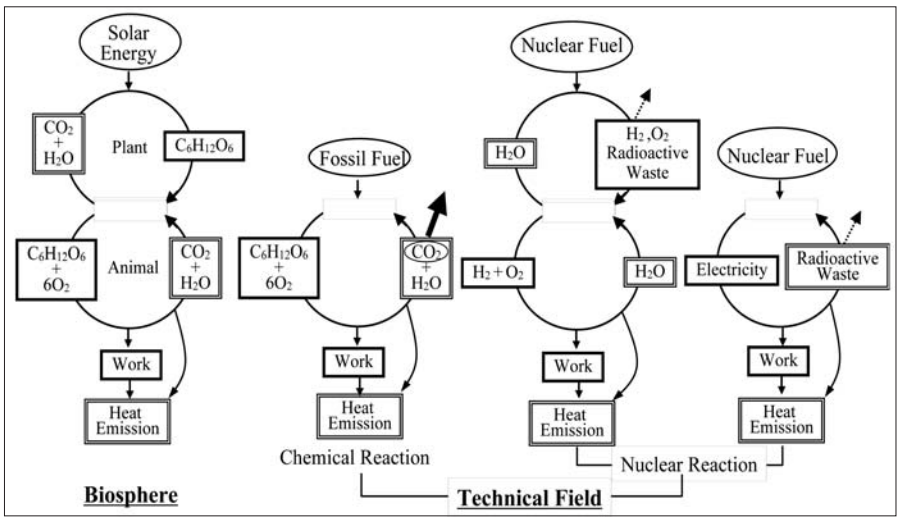

Fig. 5. Ecological and Technological Energy Systems.

developing nuclear energy in the 21st century. This can be seen from the words of *Dr. Takashi Nagai*, quoted later. Japan's readiness to bring in Western civilization, a position that has been taken since the *Meiji* Period (1868–1912), has brought us to this point, letting us follow the path of introducing light water reactors, and bringing improvements and standardization, so that the self-sufficiency rate for nuclear energy is now far ahead of other types of energy in Japan. The record of safety in light water reactors also proves that nuclear energy can be used for peaceful ends, and with absolute priority given to safety.

The introduction and stable use of light water reactors

This can be said to be a positive assessment of the record of nuclear power generation in Japan as well as advanced nuclear nations up to the present day (*Figure 6*). The introduction of light water reactors into Japanese society has certainly not been rejected, and it has secured a position as the principal electric power supply. It will be necessary to make efforts to make its position even firmer.

In fact, appeals has been made to the Japanese society for to understand and support nuclear power generation, using the slogan, "Nuclear Energy: Its Necessity and Safety" since around 1960, telling the public how important nuclear energy is for Japan, a country poor in resource, to grow into an advanced nation in the world. In the days when Japan was still a young democracy, 10 years from the end of World War II, and phrases like „candle power transmission" were used, the understanding of the people made it possible to construct power stations from the north to the south in Japan island, as it was known that electric power was not something that was easy to obtain.

After this, the first oil crisis, which hit Japan in the early 1970s, beginning with the buying up of toilet rolls in a supermarket in Senri-New town, in the suburbs of Osaka, spurred on the construction of nuclear power stations, which makes me remember that I took part in safety examinations relating to the application for a construction permit for the nuclear reactor from morning till night.

Japan's nuclear power development started from the introduction of the light water reactor, which was developed in the United States, contributing to the development of high-quality light water reactor technology through subsequent efforts for improvement and standardization, and also producing the success of constructing and operating the new type of light water reactors, in the form of large ABWRs, the 6th and 7th reactors at *Kashiwazaki-Kariwa*, and is advancing to the stage of constructing APWRs for the 3rd and 4th reactors at *Tsuruga*.

As a result of the cooperation between the government and private sector, more than 50 nuclear power reactors are now in continuous operation, which should make people in society aware that their records of operation are an assurance of safety, if not giving peace of mind.

The basic stance of Japan

The memory of Hiroshima and Nagasaki and the exclusively peaceful use of nuclear power: The nuclear non-proliferation policy is the basic attitude of Japan. Indeed, we hope for the ultimate elimination of all nuclear weapons. *Dr. T. Nagai* of *Nagasaki Medical College* stated in the "Report of the Relief Squad for Atomic Bombing Victims," in October, 1945: "Everything was finished. Our mother land was defeated. Our university had collapsed and classrooms were reduced to ashes. We, one by one, were wounded and fell. The houses we lived in were burned down, the clothes we wore were blown up, and our families were either dead or injured. What are we going to say? We only wish to never repeat this tragedy with the human race.

We should utilize the principle of the atomic bomb. Go forward in the research of atomic energy contributing to the progress of civilization. A misfortune will then be transformed to good fortune. The world civilization will change with the utilization of atomic energy. If a new and fortunate world can be made, the souls of so many victims will rest in peace."

The "No More Hiroshimas" and "No More Nagasakis" movements against atomic

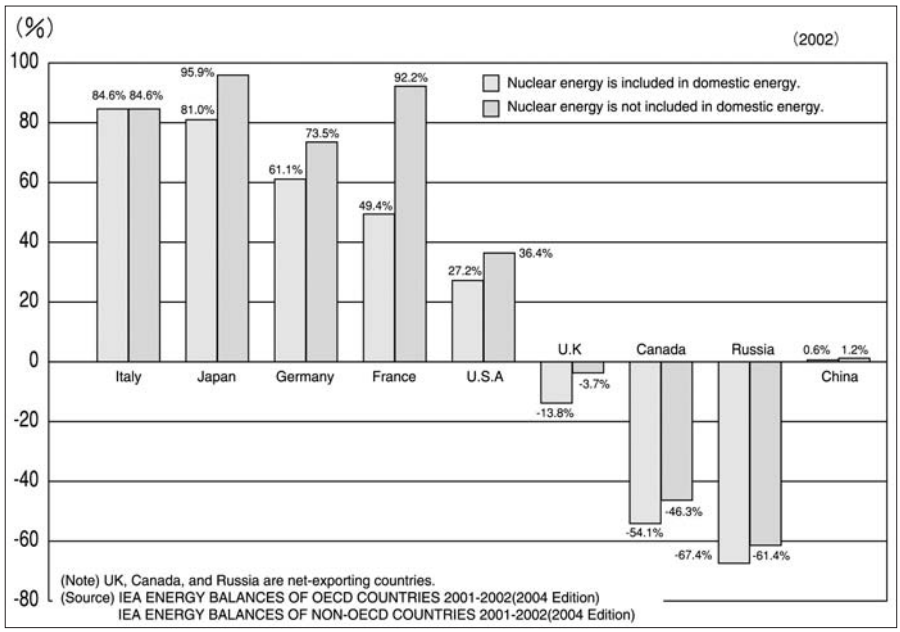

Fig. 6. Energy Self-Sufficiency Rates and Nuclear Power Production.

bombing have advanced and spread all over the world. Even now, on the anniversaries of the atomic bombings, the wish for the ultimate elimination of nuclear weapons and the opposition to atomic bombing is declared in both cities, with participation from all over the world. The tragedy of atomic bombing made both the victims of the bombing and all other people to be firmly opposed to it, but it cannot be denied that this has led to a lack of recognition that nuclear energy can have peaceful uses. Nonetheless, for me, an opposition to atomic bombing and the peaceful use of nuclear energy are in no way incompatible from the Japanese viewpoint. Indeed, I have acted believing that this stance should be the model for nuclear power development of the 21st century in the world, because I thought that it would eventually serve the best interests of the nation.

When I read the "Report of the Relief Squad for Atomic Bombing Victims" by Associate *Professor Takashi Nagai* of *Nagasaki Medical College,* I was so astonished. There are two reasons why I was astonished. First, he had a very thorough knowledge of nuclear energy. It is not certain how much knowledge of nuclear energy there was in the Japanese scientific world in those days, but he grasped the essence of nuclear energy remarkably. was further surprised that he could write these notes in October, only two months after the atomic bombing on August 9. In the midst of the chaos and enmity of the atomic bombing, when the people where far from recovered from the tragedy, he stated positively that peaceful use of nuclear energy would contribute to future civilization, and allow the minds of atomic bombing victims to rest. I was most impressed, feeling that I could have never said this, and last year I introduced the sentence of the report, translated into English, as part of my lecture delivered in the plenary session of the conference hosted jointly by *American Nuclear Society* and *European Nuclear Society* in commemoration of the 50th anniversary of the speech, "Atoms for Peace" given by former U.S. President *Eisenhower* at the United Nations.

It may be that the opposition to atomic bombing and the commitment to purely peaceful uses of nuclear energy are made possible by nuclear non-proliferation. Since mankind has already proved that nuclear energy (and radiation) can have tremendous military power when unleashed, and considering that many countries of the world, including Japan, put great energy into the military use of nuclear energy from the late 1930s to the early 1940s, it can be understood that attempts to contain nuclear proliferation, the establishment of the *IAEA (International Atomic Energy Agency)* and its activities related to safeguards have produced meaningful results and that nuclear weapons has never been used after World War II, are significant achievements. However, while the political framework is understood, it is also true that the world is not yet free from the threat of nuclear weapons, as arguments in the recent international NPT (nuclear non-proliferation treaty) conference have been contorted and nuclear bomb tests and the suspicions of nuclear capabilities still exist. While it is surely significant that power politics has meant that some countries possess nuclear weapons while others do not in the world of reality. This fact will not necessarily be readily accepted by everyone. If the major direction of development is the nuclear fuel cycle, and the possibility of nuclear non-proliferation can be studied theoretically and scientifically, and considered in constructing a nuclear energy system, this will be a significant contribution. Japan in particular could not keep uninterested in this.

Perhaps the nuclear fuel cycle became a thing of destiny when nuclear power generation underwent the drastic conversion from the gas-cooled reactor developed in the U.K., in which natural uranium is used, to the light water reactor originated in the U.S. However, we should look toward the future, starting from the position of accepting this conversion positively. The conversion from natural uranium to enriched uranium clearly represents a de-naturing of the fuel material. The scientific approach to nuclear non-proliferation should likewise be directed to the de-naturing of plutonium. This is surely one of the tasks that we should take the initiative in tackling with. A number of papers on the subject have been presented to this workshop.

4. Challenge to What the Energy System Should Be

The beginning of the new age for nuclear energy

The current age is gradually changing from a civilization dependent on chemical reaction to a civilization dependent on nuclear reaction. This new civilization wants to secure resources that will last for millennium and conserve the environment.

Development of nuclear energy seems to have moved into a new era, where the future of nuclear energy is openly discussed all around the world. The 50th anniversary of President *Eisenhower's* historic "Atoms for Peace" address to the *United Nations General Assembly* on December 8, 1953 has also provided a great opportunity to talk about the contributions that nuclear energy has made to society so far, as well as its promising future developments. International cooperation is also gaining more and more momentum.

Nuclear energy, science and technology that constitutes a fundamental pillar supporting human civilization, has the potential to make significant contributions to society in terms of energy, technology, material and information.

For example, the aim of the development of nuclear energy is to establish nuclear fuel cycles and thereby achieve a system that secures both energy supply and environmental protection at the same time.

On the other hand, the public are now becoming aware that steady progress is being made, not only in the field of nuclear energy, but also with regard to the beneficial applications of radiation. Particularly, medical applications of radiation are increasingly familiar to the general public today. It is not unreasonable, therefore, to presume that in the future it will become more and more difficult to find any area, whether in high technology or in industries, that is completely free from the influence of radiation or nuclear energy.

Taking up the challenge of establishing their ideal nuclear energy system

The development of a fourth generation nuclear energy system (GEN IV), a leading development heralding the dawn of a new age of nuclear energy, is advancing, in the form of *GIF* (the *Generation IV International Forum*), within an international framework.

The direction of development proceeding at GEN IV seems to be concentrated as follows:

a. The development of small and medium-sized nuclear reactors for flexibility in form of use.

b. Development of fast reactors.

The use of nuclear energy as an energy source can be achieved by establishing fast reactors and related fuel cycles, which satisfy the needs for securing resources and conserving the environment.

c. The development of high temperature gas-cooled reactors:

d. The development of closed fuel cycles: Hydrogen production to resemble ecological energy system.

Taking out materials that will be generated by nuclear reactions in a reactor.

There are many targets to aim at, and the forum gives one the feeling of a coming together of hopes and requests. However, the possibility of accomplishing all of what is hoped for is not being discussed. There are certainly some aspects where the balance has to be taken as a compromise, as it is impossible to pursue the best possible

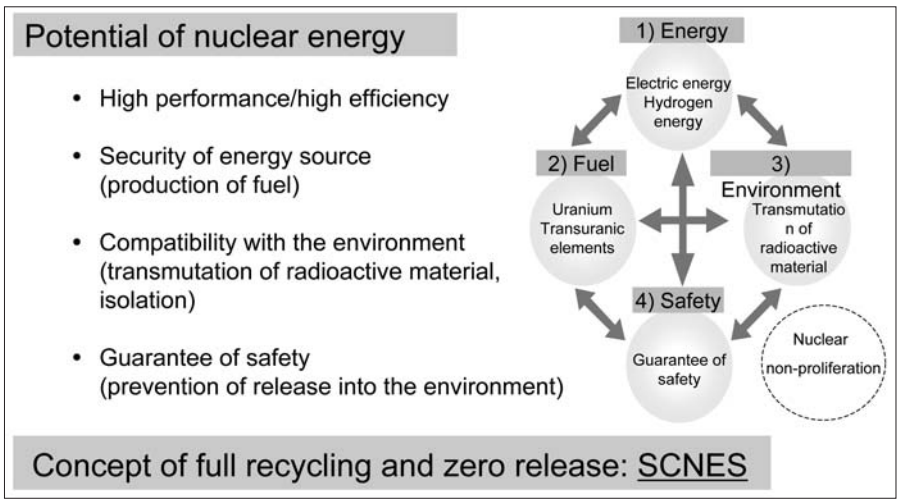

Fig. 7. The Ultimate Target of Future Nuclear Energy System. – SCNES: Self-Consistent Nuclear Energy System –

values achievable for all the different targets. An index of evaluation that allows the discussion of the assembled targets as a whole may be necessary there.

What kind of energy system can we use if we aim to construct a recycling-based society?

Put simply, this would mean producing nuclear energy using a nuclear energy system incorporating Uranium-238, and as a result only releasing stable fission products outside the system.

Is there a nuclear energy system that can succeed in completely recycling the nuclear fuel, which is suitable for a recycling-based civilization and releases zero radioactive materials at the same time? In a scientific sense, the ultimate target is to construct this within the confines of the assets of nuclear fission reactions. The scientific pursuit is to prove that this is possible using the assets possessed by nuclear fission reaction, an energy of around 200 MeV from a release of about three neutrons at each reaction. SCNES shows that this is possible, at least in the sense of scientific feasibility. The concept of SCNES that I presented in 1992 had this purpose, namely, discussing whether it would be scientifically possible to make the full use of resources and discharge no radioactive materials. In other words, it presented the question of whether it would be possible to achieve recycling and zero releases (zero emissions). *(Figure 7)*

SCNES including nuclear non-proliferation issue

The point of view taken by this discussion is to see what can be created within the confines of the assets of nuclear fission, that is, how a scientific concept can be put into practice, and using what kind of technology, and how something efficient and close to a being scientific possibility can be accomplished. To give an idea of what it should be like, light water reactors are out of the question for reasons of neutron balance, and fast neutron reactors have proved to be indispensable. It is possible to explain in physical terms whether it is possible to use resources to the full without discharging radioactive wastes and without the nuclear fuel cycle. The answer is that the required nuclear conversion cannot occur because 2.9 neutrons are not enough. To construct a nuclear fuel cycle, an energy supply is needed for the separation of elements and nuclides. Is 200 MeV enough for this?

Since it is impossible to make the radioactive material generated by nuclear fission non-radioactive using material separation at the element level, nuclide separation is needed. Here it will be necessary to introduce new technologies such as nuclear transmutation and laser separation by accelerator as well as the fast reactor.

In SCNES, the "acquisition of energy," the "acquisition of nuclear fuel" and the "attempt to make radioactive waste non-radioactive within a limited time" were carried out within the confines of the assets of nuclear fission reaction and it was confirmed that these aims were possible. At Gen4, as well as other conferences, discussions presenting a specific concept and method for pursuing this scientific target have been held, and studies are advancing on a global scale.

While SCNES has been examined as a scientific concept before, a report is now presented on a type of SCNES with a newly adopted form of fuel and core composition – no blanket – which achieves the goal of nuclear non-proliferation or at least makes nuclear proliferation difficult – the property of limited explosiveness.

Safety

The basic issues concerning safety are issues of criticalities. They include the problems of criticality occurring during an abnormality, and the problem of a recriticality occurring during a core meltdown. These are not direct issues for light water reactors, as was proved by the Three Mile Island accident, and they look set to be solved satisfactorily for fast reactors, since studies so far have been positive. The world has spent a lot of efforts investigating the problem of recriticality for a long time, and although they have been regarded as Beyond Design Basis Events (BDBEs), they have been taken up in safety examinations. A sodium-cooled fast reactor has the advantage for the property of coolability, and the issue is the problem of recriticality. We have taken up this problem, and have even arrived at the stage where the recriticality free mechanism due to early molten fuel discharge to the outer region would be demonstrated by in-pile experimental program. (*Figure 8*)

Non-proliferation

Nuclear fuels and nuclear fuel cycles with "resistivity to nuclear proliferation" have been studied before, and it is not difficult to examine the properties of nuclear non-proliferation in this framework. Given the place of use of fuel materials, they should be mobile. Therefore, it may be that it is better to dealt with this problem by looking at the composition of fuel materials rather than the space allocated to fuels. The point is finding the composition that fuel must have to satisfy the property of nuclear non-proliferation. This is why it can be said that PPP (Protected Plutonium Production) is intended to ensure the property of nuclear non-proliferation by changing the composition of materials

One extreme in the classification of nuclear fuel cycles is the PUREX process, in which plutonium can be extracted in a pure form. The other extreme is the process where it is co-extracted in a form mixed with transuranium elements contained in the spent fuel in order to lower its capability for weapon use, and, at the same time, to try to search for ways to make its conversion into weapons less easy. Pyrochemical reprocessing, as an example, starting by reprocessing metallic fuel is a typical process aimed at reinforcing the nuclear non-proliferation.

However, the discussion about finding "the requirements for a nuclear explosion or a nuclear weapon" is not a simple one, since it is sometimes argued that depleted uranium can be regarded as a nuclear weapon, or that spent fuel from a light water reactor can be converted to a nuclear weapon, and has a possibility of nuclear

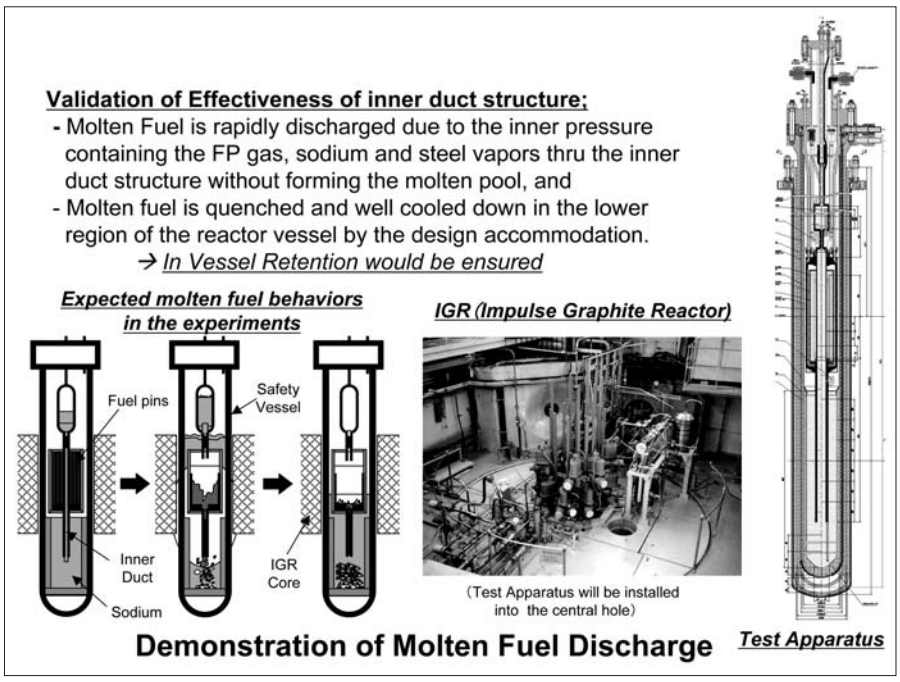

Fig. 8. Aim; Demonstration of the re-criticality free mechanism due to early molten fuel discharge to the outer region.

proliferation, and so forth. Moreover, the political implications of nuclear non-proliferation still have a big influence on world politics today, and the role of the *IAEA* is certainly a large one. It can be said that this international framework will move in the direction of international controls of the nuclear fuel cycle. It is not clear what problems may occur at this time.

Our nuclear community should now restart the discussion on nuclear non-proliferation from a scientific viewpoint at an international level. am glad to find several papers in this work shop.

5. What Can We Learn from the Nature: Universe and the Earth

The origin of nuclear energy, science and technology can be found in the universe

The existence of cosmic rays came to be discussed as the research into space and the universe advanced, and it is now at the stage where observations are made by flying balloons, and even by the measurement of neutrinos due to supernova explosions or from nuclear power stations, using a jungle of scintillation counters, as at Kamiokande.

Since elementary particles and electromagnetic wave reach the earth from the universe, as well as light, it is quite natural that the relationship between these has been focused on. Although it was not possible to understand these with traditional *Newtonian* mechanics, it was found by *Planck* and *Einstein* that they can in fact be explained by just similar expression (E=hí and $E=mc^2$), and they explained about the relationship between electromagnetic wave and the energy of a material. The field of quantum mechanics was also constructed by *Bohr*, *Heisenberg*, and *Schroedinger* and the world of nuclear energy has gradually come into view. However, it cannot yet be fully comprehended in daily life. This will take time.

The particles accelerated in an accelerator, are an imitation of the accelerator of cosmic rays, and there are advanced attempts to reproduce the origin of the universe and the birth of particles and elements. Effort is required to make people realize that there is a close interrelation between nuclear science and technology as well as differences.

Nuclear fission, nuclear fusion, particle acceleration and lasers can all be found in the universe. It will be possible to find a future for nuclear energy by learning from and imitating nature.

Can the generation of nuclear power be seen? How can the dream of science be converted into a technology and be understood? When considering phenomena in space and nuclear energy on the earth, it is important to think about what time units to use.

Cosmic time and human time

There is a special type of time for thinking about nuclear energy (*Figure 9*). While we have to think about everything in terms of human time, nuclear energy is the fundamental energy of the universe, exists in cosmic time, and there is something comparable to cosmic time in the half-life of radioactive materials. It is necessary to look at the history of the universe and other important phenomena in cosmic time, and it will be necessary to think of a way to replace the time of human society and human civilization with cosmic time, in order to continue development. In this sense, it is always necessary to think about nuclear energy by making conversions between cosmic time and human time. In human time, 10 years (a decade) is a social and

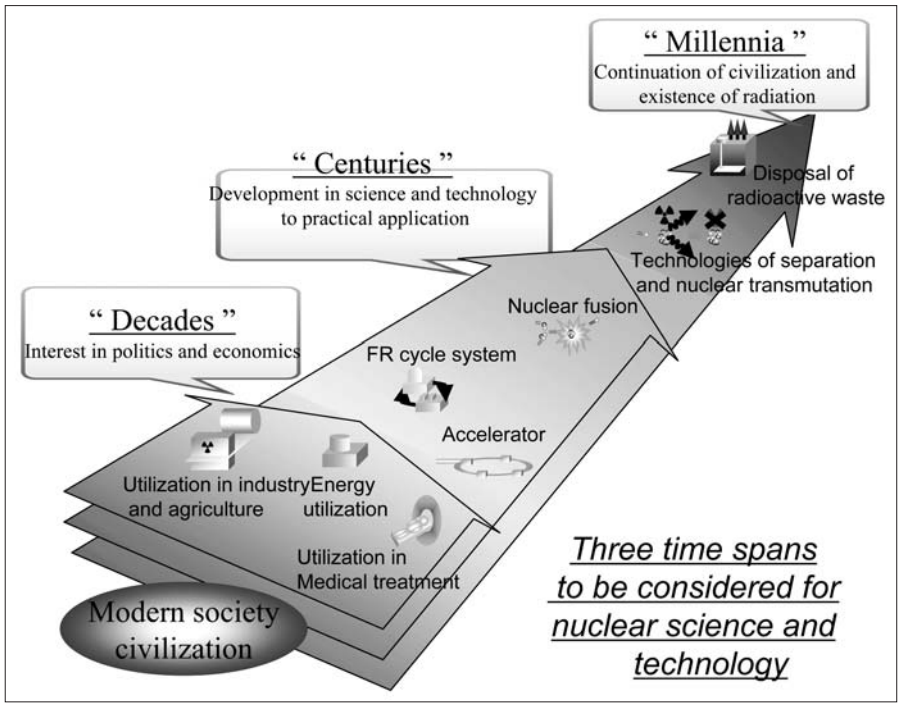

Fig. 9. The Time Span for Thinking about Nuclear Energy.

economic time, 100 years (a century) for a great piece of science to reach the stage of practical use from the start of research, and 1,000 years (a millennium) for the lifespan of a civilization can be thought of as characteristic quantities. The world of the microsecond and the nanosecond is a special world to which nuclear energy will contribute, but I am not going to address it here.

Accordingly, the discussion of radioactive waste is a subject that should be discussed using the longest time units, the length of time for which a civilization continues. It is important that the natural environment and the facts which can be seen from nature are considered fully. There are many opportunities to learn from the facts observed in the traces of natural nuclear reactors, e.g. the "natural fission reactor at *Oklo*/Gabon, the distribution of radioactive rays, the crust structure of the earth, and also human technological history, such as the history of glass since the days of the Phoenicians.

The road to comprehensive nuclear science and technology

For all of recorded history, science and technology has underpinned comfortable lifestyle (*Figure 10*). What can be expected from nuclear energy in the future? A civilization based on fossil energy was created by the introduction of artificial power and easy-to-use electric energy in the industrial revolution, and has made a comfortable lifestyle possible. The world created by a civilization based on fossil energy, which can also be called a civilization based on oil faces a turning point, as problems on the discharging side are now leading to global warming. Is it possible to solve this problem by nuclear energy, or do we have other possibilities?

Since it is not possible to have comfortable life by having an energy supply alone, mankind has depended on materials, technology (tools) and information, as well as energy, since the beginning of recorded history, although there have been big changes in the quantity and quality of these. Since the discovery of the X-ray by *Roentgen*, the areas of most advanced science have truly been opened up around radiation, in addition to energy. Is anyone other than cancer patients aware of cancer treatment by radiation? Has the situation arrived where the broad development of the science of radiation can be seen?

Nuclear energy is destined to grow into a comprehensive nuclear science and a technology which can maintain, at its roots, the whole of the civilization that has been underpinned by the fossil energy.

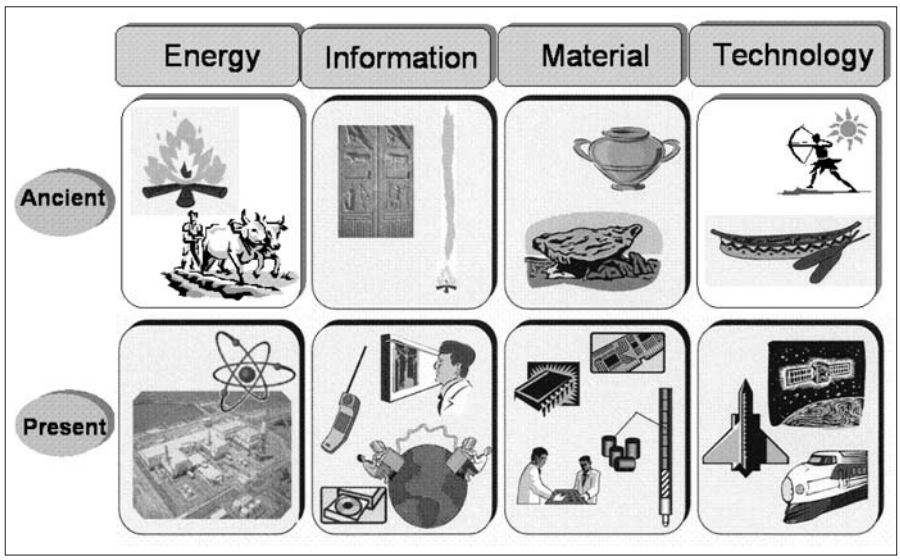

Fig. 10. What Civilization has Sought from Science and Technology?

6. Conclusion

My view of the future of nuclear energy, which I have talked about in several places before now, is, in short, "to learn from nature and imitate nature."

Phenomena similar to technology such as nuclear fission reactors, nuclear fusion reactors, accelerators and lasers, which we are trying to develop, can be seen in space. Likewise, phenomena such as the creation of elements and materials and the birth and disintegration of stars show the enormous scale of nuclear energy.

As the United Nations pointed out in the resolution concerning the sustainable development of mankind, the preservation of the ecological system that was naturally created on the earth can be understood as the result of a remarkable cooperation between the sun and the earth, in which the role to be played by nuclear energy in the future can be seen like the hydrogen production (*Figure 11*).

If the future of nuclear energy is seen from this viewpoint, it can be expected that energy resources will be secured and the environment will be conserved by a system of nuclear energy, which will hopefully grow into a comprehensive nuclear science and technology that supports the civilization at its roots.

I think that uses for nuclear fission energy will be found in studies of the commercial use and maturity of the light water reactor system, the development and commercial use of the fast reactor system and of high temperature gas-cooled reactor with the related fuel cycles. It is expected that new techniques for fuel cycles, such as a way of extracting just fission products from the spent fuel will be introduced. □

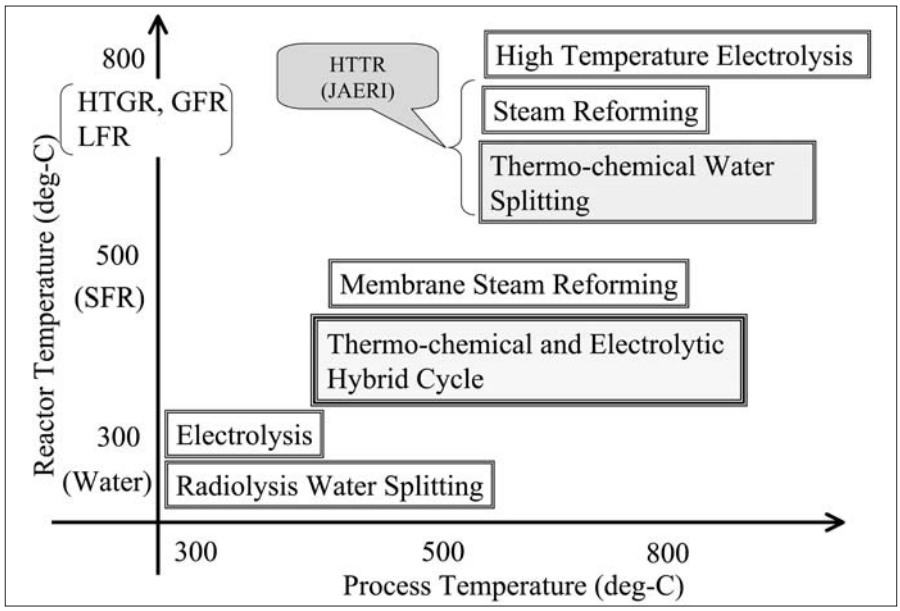

Fig. 11. Nuclear Hydrogen Production