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Review Paper

# Economic Scale of Radiation Application in Japan

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**Abstract − The economic scale of nuclear application is a good indicator to show how the radiation technology is useful and contribute to improve public welfare and living standard. Recent research in Japan shows that the economic scale of nuclear field was 4,112 B¥ for radiation application (46%) and 4,741 B¥ for nuclear energy (54%) playing a role of "two wheels of one cart" in nuclear field and the total 8,853 B¥ constitutes 1.8% of gross domestic products (GDP). The radiation application consisted of 2,295 B¥ (56%) in industry (semiconductor, sterilization, nondestructive testing, radiation processing of tires, etc.), 1,538 B¥ (37%) in medicine (therapy and diagnosis such as X-ray, nuclear medicine, computed tomography, etc.) and 279 B¥ (7%) in agriculture (mutation breeding, food irradiation, sterile insect technique, etc.). Radiation application by γ-ray, electron beam and ion beam is steadily increasing in Japan.**

**Key words : Radiation application, Economic scale, Industry, Medicine, Agriculture, Nuclear energy, Ion beam**

## INTRODUCTION

Nuclear technology such as γ-ray, electron beam (EB) and ion beam irradiation is widely used in various fields but it is not well known in public. The economic scale of nuclear application is a good indicator to show the situation of radiation technology in our life.

In 2007, the Japan Atomic Energy Agency (JAEA) had an opportunity to study an economic scale of nuclear technology in Japan on behalf of Japanese Cabinet (Japan Atomic Energy Agency 2007). The study included the nuclear energy and radiation applications in industry, medicine and agriculture. The target period of time was set to 2005. The first study on economic scales of radiation application in Japan was performed by the Japan Atomic Energy Research Institute (JAERI, presently JAEA) by a request from the Science and Technology Agency (STA, presently the Ministry of Education, Culture, Sports, Science and Technology: MEXT) in 1999 using the data of 1997 (Japan Atomic Energy Research Institute 2000). With comparison of the data in 2005 and 1997, we can know the development of nuclear techniques in Japan during these 8 years.

Up to now the γ-ray and EB are mainly used for radiation application but the application of ion beam is increasing recently. This paper reviewed the recent activities on the application of radiation through the economic scale of nuclear application in energy, industry, medicine and agriculture.

## ECONOMIC SCALE OF NUCLEAR APPLICATION

Nuclear energy and radiation are playing a role of "two wheels of one cart" in nuclear field and inseparable. The size of two wheels is measured through economic scale, that is, revenue of electricity at terminal and production cost of radi-

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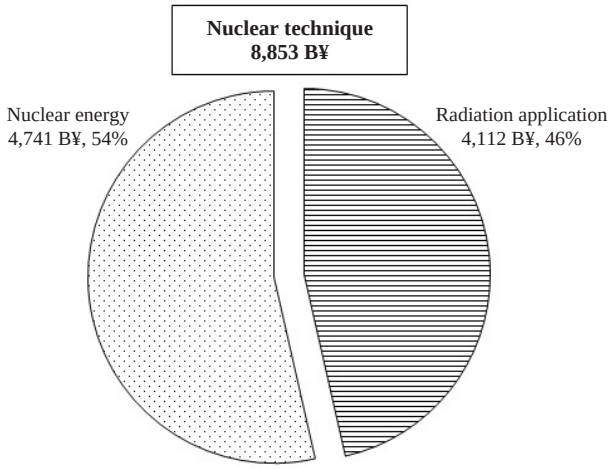


**Fig. 1.** Economic scale of nuclear technique in Japan (2005).

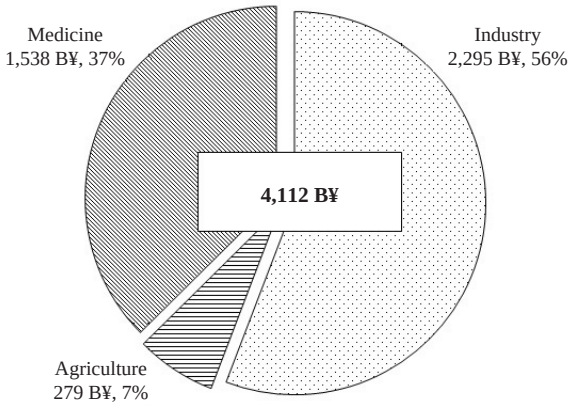


**Fig. 2.** Economic scale of radiation application.

**Table 1.** Comparison of economic scale in 2005 and 1997 (B JPY)

| | 2005 | | 1997 | |
|---|---|---|---|---|
| | Original | Recalculated* | Original | Recalculated* |
| Industry | 2,295 | 2,349 | 2,177 | 2,114 |
| Agriculture | 279 | 285 | 311 | 302 |
| Medicine | 1,538 | 1,574 | 1,246 | 1,210 |
| Total | 4,112 | 4,209 | 3,735 | 3,626 |

*Data were recalculated using the index prices (97.7 for 2005 and 103 for 1997 as calculated by 100 for 2000).

ation utilized materials at factory. The total economic scale of nuclear technology in Japan, which was estimated from public documents, was 8,853 B¥ (Billion Japanese Yen) in 2005 (Fig. 1).

The economic scale of nuclear energy was 4,741 B¥ and radiation application was 4,112 B¥. The economic scale of nuclear energy (54%) is slightly higher than that of radiation application (46%). The economic scale of nuclear energy in 1997 was 5,623 B¥ but it was decreased by the effect of accidents such as the breakdown of cooling pipe at Hamaoka power plant (2001), and secondary cooling pipe at Kansai electric company (2004), etc. In 2005, 55 nuclear power plants were in operation (49GW, 30% of electricity), 2 plants were under construction and 11 plants were under planning by 2017.

However, after the Accident of Fukushima Daiichi nuclear power station by earthquake and tsunami on 11 March 2011, many nuclear power plants were stopped the operation and the construction of new plants were under reconsideration. The effect of Fukushima nuclear accident is serious and it is, therefore, anticipated the balance of energy and radiation application breaks down due to the acceleration of braking of nuclear power.

## ECONOMIC SCALE OF RADIATION APPLICATION

The economic scale of radiation application in Japan in 2005 amounted to 4,112 B¥ in total consisting of 2,295 B¥ (56%) in industry, 1,538 B¥ (37%) in medicine and 279 B¥ (7%) in agriculture (Fig. 2).

To compare the data in 2005 and 1997, the data were recalculated using the index prices (97.7 for 2005 and 103 for 1997 as calculated by 100 for 2000). The change in economic scale of radiation application in 2005 and 1997 can be seen from Table 1. The economic scale was increased 235 B¥ in industry and 364 B¥ in medicine but it was decreased 17 B¥ in agriculture during the years of 1997 to 2005. The total economic scale of radiation application in 2005 (4,209 B¥) shows the increase of 583 B¥ during these 8 years from 1997 (3,626 B¥). From the result, it can be concluded that the radiation application is steadily increased in industry and especially in the field of medicine except the agriculture.

### 1. Application in industry

In the field of industry, the total economic scale was 2,295 B¥. The details are shown in Fig. 3; semiconductor 1,349 B¥ (60%), facility & equipment 465 B¥ (20%), measurement instruments 101 B¥ (4%), nondestructive testing 110 B¥ (5%), sterilization 170 B¥ (7%) and radiation processing 100 B¥

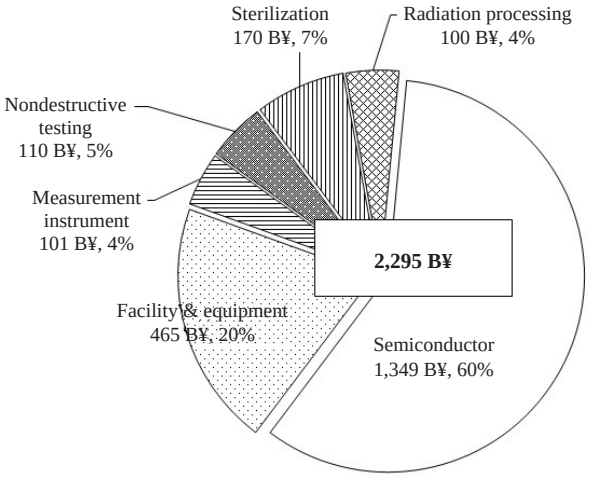


**Fig. 3.** Radiation application in industry.

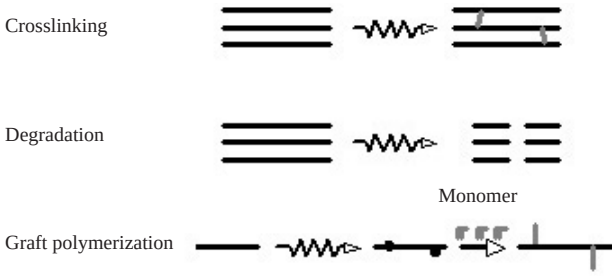


**Fig. 4.** Main reaction of polymer by radiation.

(4%).

Approximately 60% of the total production value was brought by the fabrication of IC for semiconductor. For the production of semiconductor, radiation is used in various processes such as lithographic exposure, etching, implanting, etc. The total selling value of semiconductor was 4,547 B¥ but the final economic scale was calculated as 1,349 B¥ using the 25% of radiation contribution ratio in the process.

Radiation is widely used for sterilization of medical products to avoid disease infection. The economic scale of radiation sterilization was 170 B¥ (7%). About 45% of disposable medical products are sterilized by radiation (γ-ray, 37.4% and EB, 7.9%) and the remaining are ethylene oxide (EOG) 47.2% and autoclave 7.5%. $^{60}$Co γ-rays is mainly used for radiation sterilization but high energy (10 MeV) electron accelerators are being introduced because of better public acceptance and economics for large throughput.

Radiation processing of polymers by degradation, crosslinking and graft polymerization is also the important field in industrial application (Fig. 4). The radiation crosslinking of polymers such as polyethylene, polyvinyl chloride and rubber improves their thermal resistance, chemical resistance and mechanical properties. Wires and cables insulated with radiation crosslinked heat resistant polymer are used for the automobile, telecommunications, and the aerospace instruments. Heat shrinkable material induced by crosslinking is widely used for packaging, wire insulation and corrosion protection of pipeline welds. In the automobile tire industry, radiation processing is used to crosslink rubber molecules to improve physical properties for the production of radial tires. The total production cost of radiation processing was 970 B¥. However, the final economic scale was calculated as 100 B¥ (4%) because of using the radiation contribution ratio of 4% for radial tire production (rubber weight percentage of inner liner and carcass ply where the radiation is used in the production process).

In this study, a direct effect has been estimated for the economic scale of radiation based on the sales cost of products. However, the indirect effect of radiation should be considered for the evaluation of radiation contribution to our life. For example, three main instruments such as weighing sensor by radiation, moisture sensor by infra-red and caliper sensor by laser are used in the paper and pulp manufacturing systems. The economic scale can be calculated as 1,000 B¥ from 3,000 B¥ of total selling cost. Pulp and paper are not produced directly by radiation, but without using radiation are unable to produce the product. It is required to establish the evaluation method of the indirect effect in future economic impact study.

## 2. Application in medicine

For medicine, an economic scale was studied principally by using reimbursed receipts. Those were obtainable from Ministry of Health, Labor and Welfare. In the field of medicine, the revealed amounts of 1,585 B¥ was about 4% of the national health expenditures. Majorities of those ($>$99.7%) were composed of medical care and dental care, and those were completely covered with the conventional Japanese medical security (reimbursement). A ratio between medical and dental care was 92%: 8% (Fig. 5). After the amendment of Diagnosis Procedure Combination (DPC) factor, the economic scale of medicine was estimated as 1,538 B¥.

The charged particle therapy and boron neutron capture therapy (BNCT) were very small. A radiological technology applied to medical care is diagnosis as widely known as X-

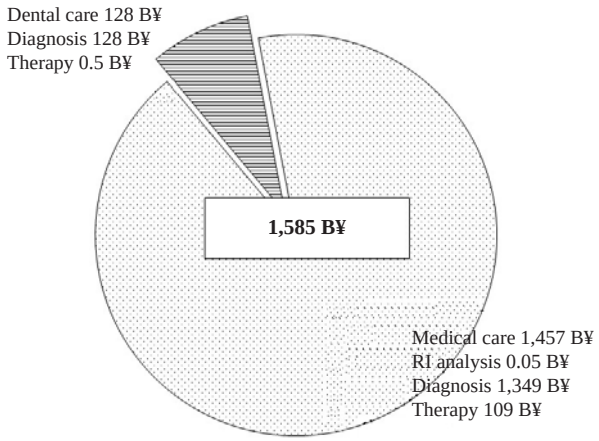


**Fig. 5.** Economic scale of radiation application in medicine.

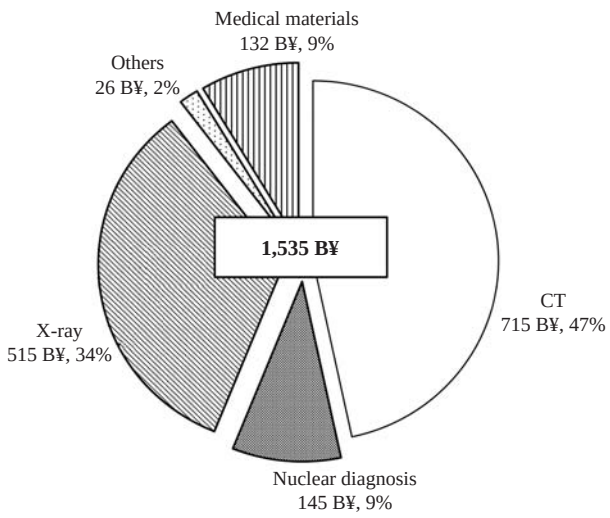


**Fig. 6.** Economic scale of diagnosis in medical care.

ray diagnosis, nuclear medicine and computed tomography (CT). In this evaluation MRI (magnetic resonance imaging) was omitted due to the non-radioactive usage. In the content of diagnosis in medical care, computed tomography (CT) and X-ray diagnosis are large in magnitude of 47% and 34% (Fig. 6).

### 3. Application in agriculture

The economic scale of radiation application in the field of agriculture in Japan was 279 B¥. In the food irradiation, the irradiated amount of 8,000 t $y^{-1}$ potatoes in Hokkaido was calculated to be 0.9 B¥. Sterile Insect Technique (SIT) for melon fly mainly in Okinawa area brought much benefit as high as 6.7 B¥. Production of rice using varieties developed by radiation mutation breeding was about 3% of overall production in Japan and the economic scale was 253.9 B¥. Radioisotope (RI) utilized in a laboratory work, environmental analysis and chronology was accounted to be as high as 14.5 B¥. The relative ratios of radiation processing, mutation breeding and RI utilization were 4%, 91% and 5%, respectively (Fig. 7).

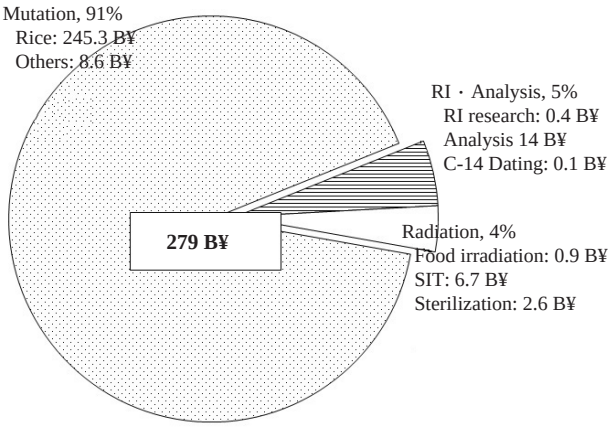


**Fig. 7.** Economic scale of radiation application in agriculture.

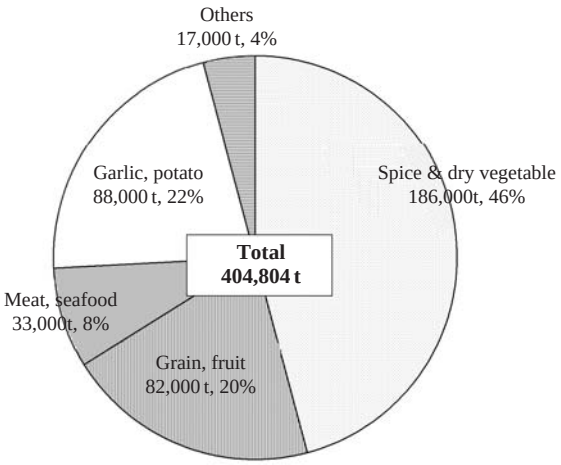


**Fig. 8.** Food irradiation in the world.

The largest field of radiation application in agriculture is mutation breeding. New mutant varieties give us useful gene resources for the security of food resources, the conservation of our ecosystem, and the promotion of new industries. The radiation-induced changes in DNA sequences have resulted improved mutant crops demonstrating 1) disease resistance, 2) early maturity, 3) drought tolerance, and 4) better yield. Plant mutation breeding by radiation has been investigating for long time in many countries. Using radiation technique,

233 varieties were developed in Japan. Many new species were developed for decease resistant crops, i.e. 70 species of rice, 8 of barley and 4 of wheat. Other species of beans, fruits including pears resistant for black spot decease, lawn grasses, vegetables, etc. were also developed.

Food irradiation in Japan is limited for potato sprout inhibition but the food irradiation is widely used in the world. Radiation reduces spoilage, improves food hygiene and kill insect pest of fruits and vegetable, replacing methyl bromide fumigation which depletes the ozone layer. The current status of food irradiation in the world in 2005 was investigated (Kume *et al*. 2009a, b). The results show that the quantity of irradiated foods in the world in 2005 was estimated as 405,000 tons consisting of 186,000 tons (46%) for disinfection of spices and dry vegetables, 82,000 tons (20%) for disinfestation of grains and fruits, 32,000 tons (8%) for disinfection of meat and fish, 88,000 tons (22%) for sprout inhibition of garlic and potato, and 17,000 tons (4%) of others including health foods, mushroom, honey, etc. (Fig. 8). The commercial food irradiation is significantly increasing in Asia but decreasing in EU because of the strict regulation of labelling.

In Japan, the quantity of irradiated potato was 8,096 tons in 2005 but it was decreased to 3,339 tons in 2006 (Fig. 9). Since the regulation for labelling was changed to put the retail each bag, the market is afraid of the boycott of consumer but it is recovered gradually year by year. The labelling is important to protect the consumer's right to choose the irradiated foods but the careful treatment is necessary to avoid the over action of consumers.

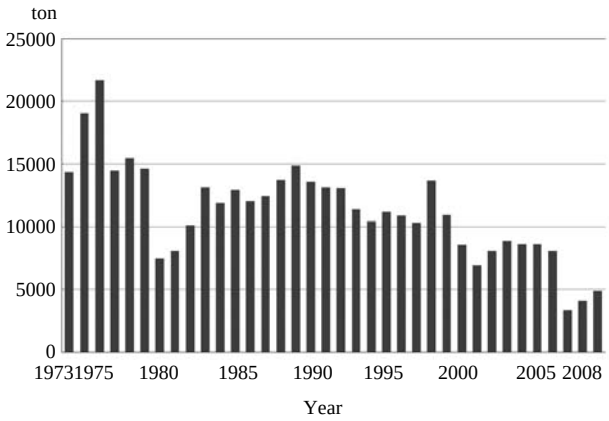


**Fig. 9.** Potato irradiation at Shihoro, Hokkaido.

## RECENT APPLICATION OF ION BEAM

The γ-rays and EB are mainly used for radiation application but the application of ion beam is increasing recently. The ion beams are widely used for the production of semiconductor and new application is increasing in therapy and mutation breeding.

In medical field, particle beams such as proton, neutron and heavy ions are used for therapy and diagnosis. For therapy, Heavy Ion Medical Accelerator (HIMAC) was installed at National Institute of Radiological Sciences (NIRS) in 1994 and more than 3,000 people have received treatment until 2007 using carbon ion with up to 430 MeV. For diagnosis, Positron Emission Tomography (PET) has been attracting attention as a tool for early cancer screening. Since PET is effective in diagnosing cancer by detecting higher levels of glucose metabolism in tumor tissues, it is called as the functional image. Since 2002, health insurance has also become applicable, the number of PET cameras in Japan has rapidly increased, i.e. 67 units in 2003, 80 units in 2004 and 138

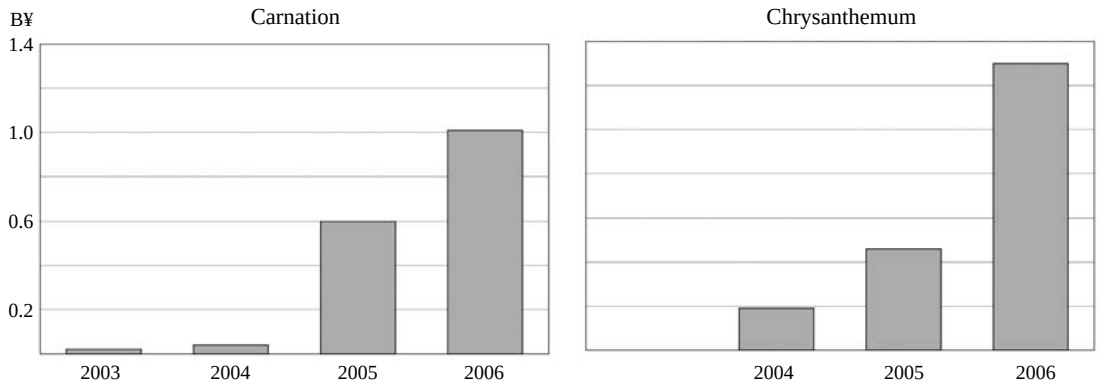


**Fig. 10.** Developmentof ion beam mutation breeding.

units in 2005. Thus the ion beam application in medical field is spread rapidly as an effective method for cancer diagnosis and therapy.

In agriculture, ion beams have been applied for mutation of plants and a lot of fascinating new mutants are generated. Takasaki Ion accelerator for Advanced Radiation Application (TIARA) has been established as the first facility of ion beams for materials and biological use in 1993. Ion beams can deposit high energy in a target densely and locally on the contrary to radiation of low LET such as γ-rays, X-ray and electron-beam. When the target is biological cells, ion beams predominantly induce single- or double-strand DNA breaks causing large DNA alterations such as inversion, translocation and large deletion rather than point mutation. The changes in DNA by ion beams have resulted in producing characteristic mutants otherwise attainable. The features of ion beams in the mutation induction seem 1) to induce mutants with high frequency, 2) to show a broad mutation spectrum, and therefore, 3) to produce novel mutants.

The ion beam irradiation has produced complex and striped flower-color mutants and new flower-shape ones that have never been induced by low LET radiation. Recently, the market of new varieties of chrysanthemum and carnation induced by ion beam irradiation has been expanded rapidly (Fig. 10). In case of improvement of chrysanthemum “Jimba”, a main standard-type white chrysanthemum variety in Japan, has been applied to establish a new variety with reducing axillary buds. Original variety has more than 30 axillary buds that must be disbudded during cultivation. New variety with a lesser number of axillary buds was successfully obtained by irradiation at JAEA-Takasaki (http://www.taka.jaea.go.jp).

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