Annex 3

# Summary of Progress Reports on Biofertilizer and Polymer Modification
# FNCA Workshop on Radiation Processing and Polymer Modification for Agricultural, Environmental and Medical Applications

November 5th - 8th 2024

Takasaki, Japan

## Session 1: Progress Report on Biofertilizer

1. Degraded Chitosan for Animal Feed, 2. Hydrogel for Medical Application, 3. Environmental Remediation, 4. Synergistic Effect among Plant Growth Promoter (PGP), Super Water Absorbent (SWA) and Biofertilizer, 5. PGP and SWA, inclusive Process development, 6. Mutation Breeding of Microbe Using Radiation, 7. Sterilization and Sanitization Using Radiation, 8. Recycle Plastic

### 1) Bangladesh (Dr. Kamruzzaman Pramanik, Bangladesh Atomic Energy Commission)

**Subject: 2**

**Short summary**

To improve the antimicrobial activity of chitosan–Ag nanoparticles, it was irradiated at different doses. Then antimicrobial activity of nanoparticles was determined against Gram positive and Gram negative bacteria. Improvement of antimicrobial activity was observed against *Staphylococcus aureus* ATCC 6538 and *Escherichia coli* ATCC 35150 strains. With increased concentration, antimicrobial activity also increased.

**Results**

Chitosan–Ag nanoparticles were prepared, and their formation was confirmed by a sharp peak occurring in the range of 410–417 nm in the UV–visible spectrum. Then nanoparticles were irradiated at 0, 5 and 10 kGy with cobalt-60 gamma irradiator. Then antimicrobial activity of irradiated nanoparticles was tested using agar well diffusion method. *Staphylococcus aureus* ATCC 6538 and *Escherichia coli* ATCC 35150 strains were used as representatives of Gram-positive and Gram-negative bacteria, respectively. Increased antimicrobial activity was observed against both strains. The antimicrobial activity was solely attributed to irradiated chitosan–Ag nanoparticles, as increasing the concentration resulted in a larger clear zone of inhibition.

**Future plan**

i) Irradiation and incorporation of chitosan–Ag nanoparticles into PVA-hydrogel and assessment of antimicrobial activity of the gel.
ii) Animal trial to check the compatibility of bioactive properties of the composite hydrogel in the animal model.
iii) Clinical trial and commercialization.

**Subject: 7**

**Short summary**

The sterilization and sanitation of medical and pharmaceutical products using ionizing radiation are

crucial aspects to ensure the safety and efficacy of healthcare interventions. Due to the increasing importance of sterilization and sanitization in the post-COVID-19 era, coupled with the demand for commercial services from various medical and pharmaceutical companies, we are focusing on launching commercial services in this sector. As part of our initiative, we initially collected samples and optimized the gamma radiation dose required for their sterilization. Additionally, we have already commenced commercial services for some products.

**Results**

Initially, we assessed the total viable count, total coliform, total salmonella, and total staphylococcal count in some samples after exposure to different gamma radiation levels (0-25 kGy). However, no growth, other than TB, was detected. Subsequently, we focused on the total bacterial count (TBC) of the supplied samples. For the sterility test, we incubated the samples after radiation exposure for 14 days in nutrient broth. No total bacterial count was observed after exposure to 6 kGy for Spirulina and 5 kGy for the Eye drop container, Plastic sample container, Gown, and Mask. Other samples did not show any count even without radiation exposure. Following the 14-day sterility test, the suggested minimum dose for sterilization for the Eye drop container, Plastic sample container, Personal protective equipment, nasal spray, Spirulina, and Camo cream was 10, 5, 5, 5, 9, and 15 kGy, respectively.

**Future plan**

- ❑ Isolation and characterization of radio-resistant bacteria
- ❑ Strain improvement of some potential isolates in near future.
- ❑ Expansion of the commercial sterilization facility
- ❑ Find out the scope of radiation sanitization of the products which does not require complete sterilization, such as Topical Antiseptics and Disinfectants, Diagnostic Reagents, Non-Invasive Medical Devices, External Packaging and Labels, Over-the-Counter (OTC) Medications, Medical Gas container, etc.

**2) China (Dr. Ruifu ZHANG, Nanjing Agricultural University)**

**Subject: 4, 6**

**Short summary**

Identification of *Trichoderma guizhouenase* NJAU4742 secreted cedrene to promote root development. Application of *Trichoderma guizhouenase* NJAU4742-based biofertilizer increased rice and maize growth and yield in saline soils. Addition of SWA increased the soil survival and root colonization of Bacterial PGPR.

**Results**

A volatile chemical cedrene was identified from biofertilzer strain *Trichoderma guizhouenase* NJAU4742, cedrene can promote lateral root development through the auxin signal pathway dependent manner, this result has been published in *Cell Reports* in 2024. Biofertilizers were applied in the saline soil, which significantly increased the crop tolerance to salt stress and the final yields. SWA was successfully prepared by radiation-induced graft polymerization of acrylic acid onto cassava starch, at room temperature and normal atmospheric pressure. The degree of swelling of SWA is 305 g/g.

Application of SWA (0.6-1:4 of the biofertilizer) with biofertilzer significantly increased the soil survival, root colonization and performance of biofertilizer in both brown and black soils, especially under the soil drought condition.

**Future plan**

1) Continued application of *Trichoderma guizhouenase* NJAU4742-based biofertilizer.

2) Synergistic of SWA and Biofertilizer in greenhouse and field plot.

**3) Japan (Prof. OKAZAKI Shin, Tokyo University of Agriculture and Technology)**

**Subject: 4**

**Short summary**

In Japan, we isolated plant growth-promoting *Bacillus pumilus* TUAT1 and commercialized it as a biofertilizer. We found that TUAT1 could inhibit the growth of some plant fungal pathogens including *Calonectria ilicicola* which causes soybean root rot disease. When we applied the TUAT1 together with oligochitosan to soybean plants, we found that the TUAT1 could alleviate the disease occurrence of soybean root rot disease and promote the growth of soybean.

**Results**

We screened and isolated plant growth-promoting strains from field soils at the Tokyo University of Agriculture and Technology (Tokyo, Japan). One of the strains, TUAT1, which was identified as *Bacillus pumilus* showed excellent plant growth promoting activities on several plants, including that of rice and Brassica species. An inoculant for rice was developed using TUAT1 that has been commercialized as “Yume-bio” in Japan.

We found that TUAT1 could inhibit the growth of some plant fungal pathogens when cultivated together in an agar plate. To understand the biocontrol activity and mechanisms of *Bacillus pumilus* TUAT1 on different plant fungal pathogens, we evaluated biocontrol spectrum and identify the biocontrol agents of TUAT1. We found that TUAT1 could inhibit the growth of several fungal pathogens. Among them, we found that TUAT1 could inhibit strongly the growth of *Calonectria ilicicola* which causes soybean root rot disease, one of the severest soybean disease in the world. On the pot experiment, we found that the TUAT1 could alleviate the disease occurrence of soybean root rot disease and promote the growth of soybean. Furthermore, additional treatments of soybean plants with oligochitosan together with TUAT1 could enhance the disease control as well as the seed production.

**Future plan**

We further analyze the biocontrol agent produced by TUAT1 for understanding the biocontrol mechanisms and further application for various crops including soybean and rice in the field. Furthermore, we plan to expand our research on useful microorganisms related to greenhouse gas reduction and wastewater treatment.

**4) Kazakhstan (Mr. Kassymzhanov Murat, JSC “Park of Nuclear Technologies”)**

**Subject: 5**

**Short summary**

Model tests on the use of superabsorbent in flower planting have been carried out. The effect of a superabsorbent on the multiplicity of irrigation of plantings has been studied. Together with the Institute of Atomic Energy, studies have been conducted on the possibility of using a superabsorbent for curing liquid radioactive waste.

**Results**

Thanks to the data obtained during model tests, it was possible to implement a project on the use of superabsorbents in landscaping the city of Kunaev. The results of the intermediate monitoring showed a high survival rate of about 90% with an average of about 50-60% for previous periods. The low survival rate is due to the very hot climate of the city of Kunaev, the average temperature in summer is about +30°C.

In the course of the work on the selection of sorbents for liquid radioactive waste, the sorbents were ranked. As a result, out of 11 types of sorbents, 3 were recommended for further studies with LRW, which demonstrated the best characteristics in the experiments with the simulator. It should be noted that when using sorbents, water was absorbed from the solution and a precipitate in the form of salt was formed. As a result of the research work on the possibility of using a superabsorbent as a sorbent for liquid radioactive waste, it was found that the best results in the sorption of LRW BN-350 were demonstrated by the sorbent "Superabsorbent". However, the main disadvantage of its use is the formation of a non-solid "gelatinous" substance, which, in principle, reduces the mobility of LRW in comparison with the liquid state, but subsequent handling of which is difficult from a technological point of view.

**Future plan**

It is planned to expand the customer base through vegetable growers, greenhouses, nurseries, and retail sales for indoor plants, garden, and vegetable garden.

**5) Malaysia (Dr. Phua Choo Kwai Hoe, Malaysian Nuclear Agency)**

**Subject: 4, 6, 7**

**Short summary**

Six biofertilizer products undergoing commercialisation. Drafting of the Malaysian Standard for Biofertilisers is underway. Effects of biofertilizers on methane ($CH_4$) and carbon dioxide ($CO_2$) emissions in rice crops have been studied. Mutagenesis involving Gram-negative and Gram-positive bacteria has been completed, while mutagenesis projects for phosphate solubilising microbes (M100) and silicate-solubilizing bacteria (SSB) are in progress. A guideline for mutagenesis (FNCA) is proposed, and the development of a gamma-sterilized carrier biofertilizer is also ongoing.

**Results**

In 2024, the commercialisation of six biofertilizer products, viz. Bioliquifert, FertiBact AP1, BioNiKPhos, SustainaBac M99, Bioliquifert M100, and Beqtoz Microbe Beads—is ongoing.

As part of a quality control plan for biofertilizer products, cooperation with the Department of Agriculture Malaysia and the Department of Standards Malaysia will lead to the drafting of a Malaysian Standard for Biofertilisers.

Research on the effect of biofertilizers on methane ($CH_4$) and carbon dioxide ($CO_2$) emissions in rice crops demonstrated that the use of M100 biofertilizer can reduce $CH_4$ emissions by 29.83% and $CO_2$ emissions by 14.13% under alternate wetting and drying (AWD) irrigation. Additionally, biofertilizers can reduce global warming potential by 21.86%.

The mutagenesis of Gram-negative and Gram-positive bacteria has been completed, and an e-book titled "Guideline on Mutagenesis of Biofertiliser Bacteria Using Gamma Irradiation" has been published. A proposal for a mutagenesis guideline (FNCA) is in development, which will include other mutagenesis methods and fungi from member countries.

Mutagenesis of phosphate solubilising microbe (M100) using gamma irradiation resulted in 83 colonies with enhanced phosphate activities. Further screening through molecular methods will be conducted to identify potential mutants of phosphate solubilising microbes.

For silicate-solubilizing bacteria (SSB), a total of 16 potential bacterial strains were isolated from various crops, with three strains (two *Enterobacter* spp. and one Bacillus sp.) showing positive results for silicate solubilising ability.

The development of biofertilizer products packed in gamma-sterilized carriers showed that of the three potential isolates inoculated on gamma-irradiated digestate carrier, only isolate B1 has a shelf life of 12 months.

In conclusion, the biofertilizer project has successfully transitioned R&D products into the market and is gaining acceptance in the country's agroindustry.

**Future plan**

The commercialisation of biofertilizers aims to encourage more crop industries to adopt their use. Development of the Malaysian Standard for Biofertilisers and the drafting of the FNCA Mutagenesis guideline will proceed. Effects of biofertilizers on methane ($CH_4$) and carbon dioxide ($CO_2$) emissions in rice crops will be further tested. In the mutagenesis project for phosphate solubilising microbe (M100), allele-specific primers will be developed to detect mutations in phosphate solubilising bacteria. For the mutagenesis of silicate-solubilising bacteria (SSB), we will evaluate the effects of SSB on rice growth and yield under glasshouse conditions, as well as determine the $LD_{50}$ for SSB mutagenesis. The development of gamma-sterilised carrier biofertilizers will continue, with ongoing tests on the shelf life of B1 isolate using various gamma-irradiated carriers, including peat, soil mixtures, zeolite, and digestate.

**6) Mongolia (Ms. Oyundalai Nyamdorj, Institute of Plant and Agricultural Science)**

**Subject: 4**

**Short summary**

The combined use of biofertilizers, PGP, and SWA supports stronger, healthier plant growth and improved crop resilience to environmental stresses. This synergy offers a promising solution for sustainable agriculture, particularly in areas prone to water scarcity. The soil moisture with SWA was higher than the control and other treatments during the growing season and post-harvest period.

**Results**

SWAs improve water retention and distribution in the soil, which helps with the breakdown of organic materials, thus promoting humus formation. The humus content of the soil was 0.1-0.7 percent higher than the control. The soil moisture was observed that single and combined treatments were better than control. All combinations of SWA were enhanced the soil moisture by 50-80% with growth and after harvesting period. With better soil moisture, SWAs support an environment where microbes can thrive. Microorganisms are key to decomposing plant and animal residues. Soil nutrients were used for plant growth, and fertilizers and other additives help increase nutrient concentrations and yield.

**Future plan**

1. Development of 2 biofertilizers based on research results in 2022-2023.
2. To study the effect of Rhizobium biofertilizers in the soil and the plants.

**7) Vietnam (Prof. Tran Minh Quynh, Vietnam Atomic Energy Institute)**

**Subject: 4, 6**

**Short summary**

From 2023, our BP Rapol-V has been approved by National Plant Protection for use in whole country, and we planned to scale up the production and expand its application for fruit plants. In parallel, *Trichoderma koningiopsis* VTCC 31435 was gamma irradiated to screen the potential antagonistic mutants for controlling the phytopathogens (*Pyricularia oryzae* and *Rhizoctonia solani*) that cause rice blast and rice sheath blight diseases in Northern Vietnam.

**Results**

The effect of Rapol-V biofertilizer growth on watermelon has been investigating in field. The preliminary results show it can slightly improve the yield of watermelon fruits. Therefore, the effectiveness of this BF will be further studied in larger areas for not only watermelon but also other fruit plants in the coming years.

The present study proved once again that gamma irradiation is a useful tool as mutagenesis to creat the microbial mutants. Gamma radiation induced the changes in morphology, growth, and antifungal activity of certain radiation-resistant colonies, leading to an increased inhibitory effect to *Rhizoctonia solani*, a common phytopathogen in rice.

At least 5 potential strains with high antagonistic abability against phytopathogen have been screened from the irradiated colonies of *T. koningiopsis* VTCC 31435. However, to substantiate this hypothesis, molecular studies of mutant strains are necessary. Furthermore, field trials are essential to assess the mutants' real-world effectiveness before considering their application in biocontrol products for agricultural purposes.

This research suggests a potential biotechnological approach to controlling fungal diseases in rice, which could significantly impact sustainable agriculture and crop protection.

**Future plan**

1. Promote the application of Rapol-V for other crop production by production on a large scale and reduce the cost.

2. Genetic stability of the Trichoderma mutant with high antagonistic capacity VTCC(a) I-1 for

investigation its activity to phytopathogen caused the rice blast and rice sheath blight diseases for rice.
3. Develop new biofertilizers composed of plant growth promotion and antagonistic microbes for controlling plant diseases.

**Session 2: Progress Report on Polymer Modification**

**1) Bangladesh (Dr. Salma Sultana, Bangladesh Atomic Energy Commission)**

**Subject: 3**

**Short summary**

Textile dyeing industries generate a large amount of effluents containing dyes which are directly discharged into the surrounding channel, agricultural fields, irrigation channels, and surface water. These effluents may cause changes in the physical, chemical, and biological properties of the aquatic environment leading to changes injurious to public health, livestock, wildlife, fish, and other biota. Thus, environmental degradation through textile dyeing effluents is a big problem in Bangladesh. Considering above those facts many researchers use techniques like precipitation, ion exchange, activated carbon adsorption, and electrolytic methods to remove dye and metal from wastewater. But all these methods have some limitations like high cost, low removal rate, difficulty for regeneration, and reuse. Therefore, many researchers focused on the alternative low cost effective hydrogel as an adsorbent. Here we developed gamma radiation induced hydrogels as adsorbent to adsorb dye and metal from aqueous solutions.

**Results**

A series of CMCh/AAm/DADMAC/MBA hydrogels were prepared by applying gamma radiation from Co-60 source for the removal of methylene blue (MB) and congo red (CR) dyes from aqueous solutions. It was observed that the Langmuir isotherm model was top fit with a high correlation (R2> 0.98) for methylene Blue adsorption and the Freundlich isotherm model was top fit (R2 > 0.97) for Congo Red. CMCh/AAm/DADMAC/MBA hydrogels, adsorption behavior followed pseudo second order kinetic model with maximum removal efficiency ~ 87% for MB whereas they followed pseudo second order kinetic model with maximum removal efficiency 91 % for CR.

A series of Starch/lignin/DMA hydrogels were prepared by applying gamma radiation from Co-60 source for the removal of methylene blue (MB) and congo red (CR) dyes from aqueous solutions. It was observed that the Freundlich isotherm model was top fit with a high correlation (R2> 0.98) for methylene Blue adsorption and the Freundlich isotherm model was top fit (R2 > 0.97) for Congo Red. Starch/lignin/DMA hydrogels, adsorption behavior followed pseudo second order kinetic model with maximum removal efficiency ~ 92% for MB whereas they followed pseudo second order kinetic model with maximum removal efficiency 69 % for CR.

In the case of industrial effluent (species-1), Na-Alg/PVP/DMA and CMCh/AAm/DADMAC/MBA blend hydrogels, removal efficiency after three (3) days are ~ 41 and ~21% and after ten (10) days are 57 and 23% respectively. In the case of industrial effluent (species-2), Na-Alg/PVP/DMA and CMCh/AAm/DADMAC/MBA blend hydrogels, removal efficiency after three (3) days are ~ 41 and ~22% and after ten (10) days are 43 and 8 % respectively.

**Future plan**

We will try to increase the dye and metal adsorbing properties of prepared hydrogels and will apply on textiles and industrial effluents.

**Subject: 8**

**Short summary**

The enormous amount of waste Terephthalate polymers, or PET, cause major environmental problems. One frequent way to recycle it is use of it as a filler material in concrete technology. However, the adhesive strength between waste polymers and the cement paste weakens with waste polymer introduction, which causes loss of some mechanical properties. One other way to deal with it is to use radiation. Accordingly, research is under progress on how waste polyethylene terephthalate (PET) and gamma radiation affects the compressive strengths (CS) of cement-based concrete.

**Results**

We are preparing concrete blocks using gravel, sand, cement and PET powder and we are using universal testing machine for mechanical strength testing. Initially the manufacturing process involved the preset ratio of 2:3:5 for cement to sand to gravel and irradiated and non-irradiated PET weighing 0.5, 1 and 1.5 g was used in place of the sand. Next, 0.5, 0.25, and less than 0.25 mm of gravel mess size were used to optimize gravel mess size. When the gravel size was less than 0.25 mm, the control, irradiated, and non-irradiated concretes showed increased compressive strengths compared to other gravel sizes. Following the selection of the gravel mess size (pan size which was less than 0.25mm) the sand was again replaced by 0.5, 1 and 1.5 g of irradiated and non-irradiated PET using three different ratios of cement, sand and gravel of 1.8:3:5, 2.2:3:5 and 2.4:3:5. Cement, sand and gravel ratio of 2.2:3:5 showed good result. Additionally, in this case, the irradiated concrete's compressive strength was higher than that of the non-irradiated concrete block. The highest compressive strength obtained was 18 MPa. 50 kGy of radiation dose was utilized in all these experiments.

**Future plan**

Now we are using PET pellets, we have plan to use PET flakes as well and we will make comparative assessment between them. We will pay effort to increase the amount of PET in the blocks more than 1.5 %. We will try to study other properties of the concrete blocks, such as workability, air content, tensile strength, and water adsorption. Irradiated and non- irradiated PET will be investigated by SEM, XRD, and FTIR.

**2) China (Dr. Hongjuan MA, Shanghai University)**

**Subject: 3**

**Short summary**

Research projects of polymer modification with irradiation technology and their applications in uranium extraction, solar-driven desalination, degradation of persistent organic pollutants and efficient treatment of microplastics were ongoing investigated. Irradiation technology with EB and $^{60}Co$ holds a huge market and demand in China and will maintain continuous growth. In addition to traditional radiation processing applications, radiation curing is particularly concerned. New materials based on radiation technology have broad application space in the future.

**Results**

1. Three-step route to prepare a covalently doped polyaniline (PANI)-based photothermal fabric with

high evaporation capacity was presented. The grafted PAA or PAM exhibited a doping effect to PANI, thus enhanced the photoelectric response and photothermal conversion ability of the obtained PANI-modified cotton fabric. This work provides a novel strategy to the enhancement of conductive polymer based photothermal materials via covalent doping, which could inspire the development of high-performance photothermal materials, thus popularizing the application of solar-driven evaporation to resource recovery from saline waters.

2. Photothermal AO-based fabric adsorbent was prepared by EB irradiation induced grafting of PAN and amidoximation of Vinyon-cotton mixture (VCM) fabric and following pyrrole-2-carboxaldehyde (P2C) dyeing, aiming to enhance the U adsorption and lower the material cost. 15-20% increase of adsorption capacity than that in dark, indicating the obvious adsorption enhancement by P2C dyeing and solar illumination. This study announces a simple and practicable route to low-cost photothermal AO-based fabric adsorbents fabrication in batch, and a low-carbon strategy to the oceanic U mining.
3. High molecular weight polyacrylonitrile (HMWPAN) fibers were utilized to prepare an economically efficient and high-performance material for uranium extraction via a pre-swollen and co-irradiation-induced graft polymerization technique. The monomer utilization ratio of AN reached 70.29%, significantly outperforming conventional methods. The method offers several advantages, including high monomer utilization, simplified post-processing, excellent material performance, and minimal homopolymer formation, all of which contribute to reduced production costs.
4. PFOS and PFOA are continuously attacked by eaq- and •H generated by EB, leading to defluorination of PFAs and the formation of other short-chain perfluoro carboxylic acids, such as PFHxA, PFPA, PFBA.
5. China's industrial electronic accelerators have developed rapidly. Electron accelerator energy covers a wide range. Application scenarios focus on these aspects: Cable, Thin film, Tyre, Heat shrinkable tube, Sheet, Sterilization of food & medical products et al.

**Future plan**

1. Research and development of new uranium extraction materials with higher capacity, fast adsorption kinetics, continue to carry out pilot scale of materials (100 kg) and marine test of uranium extraction (1 kg).
2. Assemble seawater desalination devices to solve drinking water problems for individual soldiers or fishermen.
3. Cooperate with electron accelerator companies for industrial development such as radiation curing.

**3) Indonesia (Dr. Farah Nurlidar, National Research and Innovation Agency)**

**Subject: 1, 8, 7**

**Short summary**

R&D for polymer modification using radiation process technology is conducted under Research Center for Radiation Process Technology, Research Organization for Nuclear Energy, BRIN. The research of oligochitosan for animal feed supplements was conducted through collaboration with Universiy of Padjajaran and PT Pandu Agrolestari.

Another project on recycling plastic was conducted under the collaboration with University of Indonesia, the Indonesia Recycler Plastics Association (ADUPI), and PT Viro. Now, the research is in TRL 5.
Another project is to investigate the effect of gamma and electron beam irradiation on the mechanical properties of ultra high molecular weight polyethylene (UHMWPE) based composite. The results showed that gamma irradiation up to 50 kGy tends to decrease the mechanical properties of the composite (but not significant).

**Results**

1. A start-up company, PT Ecomara Pandu Inovasi, was not eligible anymore to submit a proposal to get funding from BRIN because the requirement for the company is maximum 3 years old. Now, they will submit a new proposal through a new company, PT Pandu Agrolestari. However, they want to change the topic from oligochitosan for animal feed supplement to agriculture supplement, because they have studied that market potential for agriculture supplement is higher than that for animal feed supplement. They are planning to submit the proposal in this year, 2024.
2. Research on developing a compatibilizer from irradiated PE passed TRL 4. Now, PT Viro is conducting the experiment in large scale (50 kg) using a compatibilizer of irradiated PE. The mechanical properties measurement of thatch made with irradiated PE as a compatibilizer shows good mechanical properties compared to commercial compatibilizer.
3. Another research is to investigate the effect of gamma and electron beam irradiation on the mechanical properties of ultra high molecular weight polyethylene (UHMWPE) based composite. The composite containing UHMWPE, chitosan, and hydroxyapatite. Surface-modified UHMWPE was used to enhance the interfacial adhesion between the components in the composite. The results showed that gamma irradiation up to 50 kGy tends to decrease the mechanical properties of the composite (but not significant). However, the mechanical properties of the composite made from surface-modified UHMWPE are significantly smaller than that composite made from UHMWPE. Therefore, in this research we are modifying UHMWPE using gamma/electron beam in order to generate oxidized group in the UHMWPE, thus the UHMWPE can be compatible with hydrophylic compounds, such as chitosan, and hydroxyapatite.

**Future plan**

- Support PT Pandu Agrolestari to get funding from BRIN for down streaming the oligochitosan as an animal feed supplement through a research-based start-up company
- Continuing to reach the TRL 5 of the development of a compatibilizer generated from irradiated recycled PE to be used in wood plastics composite.
- Continuing to get a complete data sheet on the effect of gamma and electron beam irradiation on the sterilization of UHMWPE based composite

**4) Japan (Dr. TAGUCHI Mitsumasa, National Institutes for Quantum Science and Technology)**

**Subject: 2, 3**

**Short summary**

Our research aim is to create highly original and functional biodevices by ionizing radiations. The

microtopography and physical and chemical properties of the biomaterials can be freely and three-dimensionally controlled from nm to μm by utilizing the uniqueness and superiority of radiations. We are conducting research and development of cutting-edge medical devices such as three-dimensional cell culture substrates, and nanosensors based on biocompatible polymers.

**Results**

1) Smart gelatin nanoparticles

Aqueous gelatin solutions were irradiated with γ-rays to produce nanoparticles with average diameters of 5–20 nm by a radiation crosslinking technique. The gelatin nanoparticles were labeled with $^{64}$Cu, exhibiting negative surface potentials. Then, the nanoparticles were evaluated *in vivo* by injecting them into pancreatic tumor-bearing mice. Notably, the nanoparticles accumulated in the tumors. $^{64}$Cu-labeled gelatin nanoparticles show promise as a platform for next-generation PET imaging agents for pancreatic cancer.

2) Environment-friendly bio-materials

Highly transparent hydrogels based on hydroxypropyl cellulose were prepared via the radiation crosslinking technique using electron beams. By optimizing the irradiation dose and type of added monomer, excellent physicochemical properties, such as mechanical strength and transparency, and biological properties, such as low lysozyme deposition and biodegradability, were obtained. The produced hydrogels can be potentially used as human- and environment-friendly soft contact lenses materials.

**Future plan**

We investigate the radiation crosslinking technique to develop functional bio-devices in medical applications. Specifically, we aim to develop 3D cell culture hydrogels for drug discovery and regenerative medicine, nanosensors for diagnosis, and microfluidic chips for rapid and accurate drug evaluation, and implement into society.

**5) Kazakhstan (Mr. Nurkassimov Azat Kanatovich, JSC "Park of Nuclear Technologies)**

**Subject: 3**

**Short summary**

During the research work, the dependences of changes in the structure and physical and mechanical properties of the PE-100 polymer modified by the radiation method at the ELV-4 electron accelerator were studied, and the dependences of the thermal properties of the modified polymer on the radiation dose were obtained.

**Results**

The patterns of formation of the spatial-network structure of PE during radiation treatment have been established; in the control sample, the degree of crosslinking is about 70%, after the modification process, this same figure is about 80%.

Relaxation processes of pipe samples of polyethylene cross-linked by various methods in the constant deformation mode were studied. It was shown that the relaxation rate constants at 90 and 110°C for radiation-cross-linked PE are higher than those of the control sample, which leads to an increase in the

stability of properties and a decrease in the level of internal stresses.

Based on the analysis of long-term test results, the estimated service life of cross-linked PE pipes was established, laboratory and full-scale tests were conducted, and regulatory and technical documentation was developed. Industrial production of radiation-cross-linked hot water supply and heating pipes, characterized by a large safety margin relative to the estimated pressure at temperatures up to 95°C, was mastered.

**Future plan**

Based on the results obtained, it is planned to establish the production of modified pipes for hot supply. It is planned to purchase industrial equipment within the framework of grant financing from JSC Science Fund.

A scientific article is also being prepared for publication in peer-reviewed journals.

**6) Malaysia (Ms. Maznah Binti Mahmud, Malaysian Nuclear Agency)**

**Subject: 1, 4, 5**

**Short summary**

Gamma radiation is utilized in the preparation of KitogGama, CarraPGP, and SWA-sago. The processes for creating these products have been established, and their potential applications in aquaculture and agriculture have been demonstrated. To ensure high-quality end products, ongoing studies are focused on assessing product stability and performance. For the efficiency test, further collaboration and partnership with professionals from agricultural backgrounds should be pursued. Engaging in this type of work will help promote the products effectively.

**Results**

KitoGama is a chitosan-based animal feed supplement that has demonstrated promising results in aquaponic systems, particularly with crops such as chili, tomato, brinjal, and water spinach. The application of KitoGama resulted in increased nutrient levels of nitrogen (N), phosphorus (P), and potassium (K) at 224 ppm, 329 ppm, and 502 ppm, respectively, compared to AB fertilizer, which provided 142 ppm, 260 ppm, and 479 ppm. Additionally, the electrical conductivity (EC) readings were higher when using KitoGama compared to AB fertilizer.

SWA-sago prepared at 25 kGy exhibited the highest swelling capacity. This SWA-sago was soaked for varying durations and subsequently used in germination tests for Sacha Inchi seeds. The results showed that after soaking for 3, 6, and 12 hours, SWA-sago provided sufficient moisture for seed germination for up to 27 days without additional watering. Specifically, with a 3-hour soaking period, the seeds began to germinate by day 6 of the treatment.

As the irradiation dose increased, the pH of the carrageenan solution decreased. Additionally, the incorporation of preservatives further lowered the pH of these solutions. Highly acidic conditions in planting media can lead to nutrient deficiencies, which hinder seed germination and growth. To mitigate this issue, the pH of CarraPGP is adjusted to approximately 5. CarraPGP, with an average molecular weight of around 9.43 kDa, has demonstrated significant improvements in germination rates, seed survivability, plant height, and dry biomass. In contrast, carrageenan with a molecular weight of 3.18

kDa showed reduced growth-promoting activity.

**Future plan**

a. Partnering with NGOs to conduct experimental and field trials.

b. Collaborating with researchers from the Agrotech Division to develop methodologies for product application that enhance productivity while aligning with local farming practices.

c. Investigating the impact of biofertilizers on methane ($CH_4$) and carbon dioxide ($CO_2$) emissions in rice cultivation using organic fertilizers and CarraPGP.

d. Developing standard operating procedures for product preparation and application.

e. Identifying potential clients for product scaling and commercialization efforts.

**7) Mongolia (Dr. Chinzorig Radnaabazar, National University of Mongolia)**

**Subject: 7**

**Short summary**

Locally grown potatoes were irradiated by low-energy X-rays with various low doses (up to 200 Gy). Single-side irradiation was carried out and dose uniformity within potatoes has not been considered in this study. Other studies have suggested that lower doses of irradiation can actually make potatoes more susceptible to rotting, even during low-temperature storage. To test this theory, we incubated both irradiated and non-irradiated potatoes at room temperature (22°C). We observed significant differences between the two groups, including measurable physical-mechanical and biochemical changes. Based on our results, it can be inferred that before storing potatoes at room temperature, 150 Gy X-ray irradiation is the most suitable for cv. gala variety.

**Method and materials:**

Well-shaped, damage-free, firm, and relatively clean potatoes (Solanum tuberosum' L. (Family: Solanaceae), cv. 'gala') was divided into 4 groups, and 3 groups were irradiated with 100 Gy, 150 Gy, and 200 Gy doses using RS1800 Q4 X-ray irradiator. Irradiated samples were incubated at room temperature for 60 days and measured changes in weight, length, width, sprouts, green and browning area of each potato according to MNS 0258:2021 standard. Total sugar, dissolved solids and pH were measured and compared in each group. In this study, we have used X-ray cell irradiator, Rad Source RS1800, was designed to be a compact, self-containing cell irradiation research system and has operating voltages between 40 and 160 kV [3]. Dose mapping was conducted using PTW Unidos 10002 electrometer and PTW30004 ionization chamber and showed good agreement with the reference value provided by manufacturer

**Results**

There are notable differences in the sprouting of potatoes even when exposed to similar levels of irradiation (as shown in Figure 4). In the control group, the average number of sprouts per potato was 7.25±1.25, whereas in the 150 Gy group, the average was 4.17±1.01. The most significant difference in sprouting was observed in the control group, where the average number of sprouts that were longer than 4mm was 2.88±0.88, a phenomenon that did not occur in the irradiated potato groups. When a potato sprouts more than 5%, it is not acceptable according to the Mongolian standard MNS 0258:2021. The

pH of both irradiated and non-irradiated groups was within the normal range of pH 5.1-5.9 after being stored at room temperature for 60 days.

Based on the TPA results, it was found that after 60 days of storage, the control group of potatoes was less hard by 40-50 N as compared to the groups of irradiated potatoes, and their gumminess was also 10-20 N less. On the other hand, the puncture force was similar for all groups, but the work done, puncture stroke and Young's modulus values were significantly different between the control and irradiated groups. For instance, the 'work done' parameter values of the control group were 20-50 mJ higher compared to the other groups. The puncture stroke was also 2 mm more for the control group, while the elasticity modulus of the control group was 1000-2000 Pa lower. Consequently, it can be concluded that the properties of potatoes stored at room temperature for 60 days after irradiation at different doses differ from those of non-irradiated ones.

**Future plan**

a. Post-harvest treatment of basic vegetables (carrot) with irradiation to reduce losses during preservation.
b. Meat treatment to improve hygiene and sanitation.
c. Promote and educate farmers and small businesses, provide nuclear technological information to the public as a safe.

**8) The Philippines (Dr. Charito T. Aranilla, Ms. Lorna Relleve, Philippine Nuclear Research Institute)**

**Subject: 2**

**Short summary**

1. CMC Hemostats

The Clinical Trial Protocol for CMC hemostats has received approval from the Ethics Review Boards of East Avenue Medical Center and V. Luna Medical Center. FDA approval will be the next milestone for trial execution. Initial pilot-scale production of CMC hemostats was conducted in an FDA-certified facility, with samples prepared for FDA Certification of Medical Listing and restricted to clinical use.

2. CMHA Hydrogels for Drug Delivery and Wound Healing

Carboxymethyl hyaluronic acid (CMHA) hydrogels have been synthesized by gamma and electron beam irradiation. Their properties were characterized, including their stimuli-responsive swelling behavior. Potential applications of CMHA hydrogels in colon-targeted drug delivery and wound healing are currently being explored.

**Results**

1. CMC Hemostats

The pilot-scale production of the CMC hemostats was initiated with 50 kg paste produced per batch packed at 25 kg/pouch. The samples were irradiated with gamma at 40 kGy. The gel fraction and degree of swelling were 39% and 370 g water/g dry gel, respectively. The production of the granules-infused gauze has been demonstrated to the toll manufacturer, and the preparation of 200 pcs of granules-infused gauze will be started soon.

2. CMHA Hydrogels for Drug Delivery and Wound Healing

CMHA hydrogels were prepared at 40% and 60% concentrations, achieving a gel fraction of 40-65% with doses of 40-120 kGy. At an extremely low dose rate (0.5 kGy/h), hydrogels could not be formed at 10 or 20% concentration. However, when using electron beam irradiation and gamma with a dose rate of 2 kGy/h, the formation of hydrogels was achieved at 20% concentration. FTIR and TGA analyses revealed some structural changes in the hydrogels at higher doses. The hydrogels exhibited a remarkable swelling capacity ranging from 40-2400 g water/g dry gel and exhibited a pH and salt-responsive swelling behavior. Cytotoxicity testing showed that CMHA hydrogels prepared at 60 and 120 kGy have excellent biocompatibility, with almost 100% cell viability. The application of CMHA hydrogels in drug delivery commenced with diclofenac as a model drug. Results indicated that the drug loading capacity and in-vitro drug release profile of CMHA hydrogels were comparable to those of hydrogels developed by other institutions. On the other hand, degradation studies were carried out at 1% solution using gamma-irradiation for wound healing application. At 100 kGy, a molecular weight of about 4000 Da was obtained. Increasing the dose to 200 kGy did not reduce the molecular weight further. Cytotoxicity testing indicates that CMHA oligosaccharides demonstrate excellent biocompatibility, with cell viability values exceeding 70%. Antioxidant activity increases with irradiation dose; however, ascorbic acid has better antioxidant properties.

**Future plan**

1. CMC Hemostats
   - Continuation of pilot-scale production trial
   - Verification and Substantiation 25 kGy as Sterilization Dose
   - Initiation of Pilot Clinical Trial

2. CMHA DDS
   - Continuation of drug delivery studies on diclofenac
   - Initiation of studies on chemotherapeutic drugs such as oxaliplatin and 5-fluorouracil
   - Outsourcing of angiogenesis and wound healing assays

**9) Thailand (Dr. Kasinee Hemvichian, Thailand Institute of Nuclear Technology)**

**Subject: 5**

**Short summary**

Previously, SWA hydrogel was successfully prepared. Results from the field tests revealed that the prepared SWA was able to increase the survival rate of young rubber trees planted in arid area by up to 40%. However, the method used for SWA hydrogel production consumes a lot of time and energy, while producing SWA hydrogel is produced in irregular sizes and shapes. This research aims to develop a novel method to fabricate SWA in uniform size and shape.

**Results**

A new method was developed to prepare SWA in uniform size and shape. SWA beads were successfully prepared via radiation-induced graft polymerization of AA onto alginate-cassava starch beads. The

prepared SWA beads a high swelling ratio of 360 g/g. The results from this study have proved that this new method can prepare SWA beads in uniform shape and size, while saving both energy and time.

**Future plan**

1. Field tests of SWA beads are being performed in order to analyze their potential for agricultural applications.
2. Expanding utilization of chitosan from plant growth promoter (PGP) to other applications (chitosan beads for encapsulation of essential oils, degraded chitosan for animal feed, chitosan-based coating film)

**10) Vietnam (Prof. Nguyen Ngoc Duy, Vietnam Atomic Energy Institute)**

**Subject: 3, 8**

**Short summary**

- Plastic waste from lobster nets was enhanced in mechanical properties by Co-60 gamma irradiation and combined with high-density polyethylene (HDPE) for recycling. Gamma irradiation at various doses (15, 20, 25, and 30 kGy) showed that a dose of 15 kGy optimized the mechanical properties of the plastic waste. The irradiated plastic was then mixed with virgin HDPE at ratios of 10:90, 20:80, and 30:70. The results showed that the 20:80 (waste-to-virgin HDPE) blend exhibited the best of properties.
- The study describes the preparation of PVDF-g-AAc (polyvinylidene fluoride grafted with acrylic acid) membranes using two irradiation methods, specifically modified with silver (Ag) and copper (Cu) to enhance their properties. These PVDF-g-AAc-Ag and PVDF-g-AAc-Cu membranes demonstrated significant bactericidal effects, particularly against *E. coli* bacteria. Given the strong antibacterial performance of the PVDF-g-AAc/AgNPs (silver nanoparticles) membrane, it shows promise for application in water treatment.

**Results**

- This study focuses on recycling plastic waste from aquaculture, specifically lobster nets, by enhancing the mechanical properties of the recycled material through Co-60 gamma irradiation. The recycled HDPE plates were exposed to different doses of Co-60 gamma radiation: 15, 20, 25, and 30 kGy. Among the doses tested, 15 kGy proved to be the optimal dose for crosslinking, showing the best mechanical stability. The irradiated recycled HDPE at 15 kGy was blended with virgin HDPE in three different ratios: 10:90, 20:80, and 30:70. These mixtures were tested to determine the best combination for mechanical performance. Mechanical properties, including melt flow index, impact strength, flexural strength, and tensile strength, were evaluated for each blend ratio. The 20:80 blend ratio (recycled HDPE to virgin HDPE) demonstrated the best combination of mechanical properties, making it suitable for potential commercial applications in recycled HDPE products.
- PVDF-g-AAc membranes were fabricated by pre-irradiation method at a radiation dose of 20 kGy for 5 hours to achieve an AAc grafting degree of 1.5% and simultaneous irradiation method at a radiation dose of 10 kGy achieved the degree of AAc grafting was 22%. The PVDF-g-AAc membrane in this study was functionalized with silver (AgNPs) and copper nanoparticles (CuNPs),

with contents determined at 4.21% by weight for AgNPs and 0.58% by weight for CuNPs. The PVDF-g-AAc membrane embedded with AgNPs demonstrated significant antibacterial effectiveness. In two tested methods, it showed antibacterial effectiveness rates of 89.49% and 98.99%, respectively, indicating a high bactericidal effect. The membrane with CuNPs showed lower antibacterial effectiveness, with rates of 27.62% and 38.53% in the two methods, respectively. The results suggest that PVDF-g-AAc membranes embedded with AgNPs are more suitable for applications requiring strong antibacterial activity, such as water treatment or medical filtration, compared to those embedded with CuNPs.

**Future plan**

- Study on the treatment of hospital wastewater treatment using electron beam method.
- Study on the increase of mechanical properties of plastic waste (mesh waste) using irradiation for recycle purposes at pilot scale
- Study on the fabrication of nanogels by the electron beam irradiation method from natural polymers for applications in medicine