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# The effect of chemical commitments with exposure to gamma irradiation dosage and save time on test attraction and pullet limits of HDPE pack

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**Abstract.** This study aims to determine the effect of gamma irradiation doses and time of storage on the mechanical properties of HDPE packaging plastics, and to apply gamma irradiation techniques to improve the mechanical quality of materials, especially plastic-based products. Packaging plastic is the most popular packaging material used, many businesses choose plastic as packaging for their products Research Place for Polymer laboratories, Isotopes and Radiation Technology Application Centers, National Nuclear Energy Agency, Pasar Jumat, South Jakarta and Mechanical Test Laboratory of the faculty of Engineering, UHAMKA Pasar Rebo, East Jakarta. To determine the resistance of packaging plastic to gamma irradiation, the effect of gamma irradiation dosage and storage time on the mechanical properties of HDPE plastic packaging were carried out. The research will be conducted with Cobalt-60 gamma radiation sources at irradiation doses of 10, 15, 20, 25, and 30 kGy with a dose rate of 6 kGy / hour, then some irradiated plastic footage is stored at room temperature for 0 and 5 weeks. The mechanical properties tested were yield strength, tensile strength, and elongation at break using the strograph R1 tensile test tool. Gamma irradiation caused yield strength, tensile strength and elongation in the A brand HDPE packaging plastic increased from 0 to 5 kGy, then decreased by 5.31% at a dose of 10 kGy and then continued to increase to a dose of 25 kGy. The optimum increase occurred from doses 15 to 20 kGy, as much as 12.00%. For plastic B, the breakout extension (Eb) continues to increase as the irradiation dose increases to 30 kGy. The optimum Eb increase occurs from a dose of 0 to 5 kGy, at 9.80%. Increased mechanical properties are caused by free radical species formed during the irradiation process, so that a cross-bond is formed between HDPE plastic packaging molecules. While the decrease occurs due to the weakening of the cross bond between the HDPE packaging plastic molecules.

## 1. Introduction

Packaging plastic is the most popular packaging material used. Many businesses choose plastic as packaging for their products. This is because plastic has superior properties such as strong but light, inert, not corroding, thermoplastic (soft when heated and hardened when cooled), and can be labeled or molded with various creations.

At this time, packaging plastic is widely used to meet various needs so that the plastic gets various treatments. In addition, there are also various types, shapes and thicknesses that are very diverse. Packaging plastic used with the intention of protecting, marking, improving the appearance and wrapping of goods. The types of packaging plastic that are widely available on the market are in the



form of bag films, including raw materials from LDPE (Low Density Polyethylene), HDPE (High Density Polyethylene), PP (Polypropylene) and OPP (Oriented Polypropylene).

The four raw materials for making packaging plastic, they have various weaknesses and advantages, but the application depends on its basic properties so that it will affect its mechanical properties. HDPE (High Density Polyethylene) is a polyethylene with high density / density which is 941 - 965 kg / m<sup>3</sup>, as packaging material has a visually not clear (opaque) is rigid, less elastic but strong and heat resistant [1].

Research and development of HDPE experienced rapid progress, one of which was the application of irradiation techniques that could be used in packaging plastic. According to Winarno et al., (1980), irradiation is a technique of using energy to irradiate materials using artificial irradiation sources [2]. In general, irradiation techniques are the transmission of energy with radiation (for example gamma rays) of high intensity and do not make the material that receives radiation energy become radioactive

Today, the application of radioisotope (gamma) utilization is increasingly developing in Indonesia and is widely used in various fields, such as agriculture, animal husbandry, medicine, industry, hydrology, and food [3]. Gamma irradiation of HDPE packaging plastic is one example of application in the industrial field. The application of high energy radiation to the synthesis and modification of polymers (plastics) is based on the fact that high energy radiation has the ability to produce free radicals that begin with chemical reactions [4].

Previous studies showed that gamma irradiation affected the mechanical properties of polyethylene and polypropylene based packaging plastic, namely increasing tensile strength and decreasing break elongation [5]. In the study also stated that packaging plastic that has been irradiated by gamma, then stored for a certain period of time also undergoes changes in mechanical properties.

Based on this research, the effect of gamma irradiation dosage and the time saved on the mechanical properties of HDPE type plastic packaging was observed. Testing of mechanical properties include elongation break, tensile stress, and yield strength. In line with the increasing standard of living, there will also be an increase in demand for plastic-based materials. This requires the latest plastic processing technology in an effort to obtain goods of reliable quality.

This study measured the mechanical properties of HDPE packaging plastic before and after irradiation. Irradiation was carried out at radiation doses of 5, 10, 15, 20, and 25 kGy. Testing the mechanical properties of HDPE packaging plastic is carried out after storage within 1 and 2 consecutive weeks. The mechanical properties tested included tensile strength, yield strength, and elongation break. Plastics are part of hydrocarbon molecules which are the basic constituents of carbon and hydrogen. At present there are mainly six widely used polymer commodities, they are polyethylene, polypropylene, polyvinyl chloride, polyethylene terephthalate, polystyrene, and polycarbonate. They make up 98% of all polymers and plastics found in everyday life. Each of these polymers has degradation and heat, light and chemical properties.

Plastics are long-chain polymers from atoms that bind to one another. This chain forms many repetitive molecular units, or monomers. The main component of plastic before forming a polymer is a monomer, the shortest chain. Polymers are a combination of several monomers that will form a very long chain. If the same monomer is called homopolymer, and if the monomer is different it will produce a copolymer [6]. Materials made from plastic from oil and gas as a natural source, in its development are replaced by synthetic materials so that the desired properties of plastic can be obtained by copolymerization, lamination, and extrusion. When chains of plastic monomers are grouped together in a random pattern, resembling a haystack it is called amorp, if it is organized almost parallel it is called crystalline with harder and harder properties. Classification of plastic according to its chemical structure is divided into two types, namely:

1. Linear, if a monomer forms a straight (linear) polymer chain, a thermoplastic plastic will form which has the property of melting at a certain temperature, adhering to changes in temperature and reversible to its nature, which is hardened again when cooled.

2. Three-dimensional network, if the three-dimensional monomers are due to chain polymerization, thermosetting plastic will be formed with properties irreversible. If once hardening has occurred, the material cannot be softened again [7].

Thermoplastics are plastic that can be softened repeatedly using heat, including polyethylene, polypropylene, polystyrene and polyvinylchloride. The best thermoplastic plastic for packaging is that has a freezing point below 00C, a melting temperature above 1000C. [8] While thermosets are plastic that cannot be softened by heating, including bakelit, phenol formaldehyde and urea formaldehyde. Thermosetting plastics are usually hard because they have cross bonds. Thermoset plastic becomes harder when heated because the heat causes cross bonds to form more easily. Thermoset type plastic is not very attractive in the recycling process because in addition to difficult handling, the volume is far less (around 10%) than the volume of thermoplastic plastic types [9].

Material mechanical properties, is one of the most important factors underlying the selection of materials in a design. Mechanical properties can be interpreted as a response or material behavior to the given load, either in the form of force, torque or a combination of both [10]. In practice loading on materials is divided into two, namely static load and dynamic load. The difference between the two is only in the time function where the static load is not affected by the time function while the dynamic load is influenced by the time function.

Radiation is a general term for all types of energy emitted without media. Radiation is the emission of energy through matter or space in the form of heat, particles or electromagnetic / light waves (photons) from the radiation source. There are several radiation sources that we know around our lives, for example television, lighting, food heaters (microwaves), computers, and so on. Irradiation is a physical process that can be used to improve the quality of a material. The type of radiation used is high-energy radiation called ionizing radiation, because it causes ionization in the material it passes.

According to Winarno et al. , irradiation is a technique of using energy to irradiate materials using artificial irradiation sources. According to Ivanov, gamma ray irradiation is a beam of high-energy electromagnetic waves in the form of energy packs (photons) [11]. In general, irradiation techniques are the transmission of energy with radiation (eg gamma rays) of high intensity and not making the material that receives radiation energy become radioactive.

## 2. Research methods

The methodology used in conducting this research is the experimental method used to prove the truth of the hypothesis through experiments carried out in polymer laboratories, Isotopes and Radiation Technology Application Centers, National Nuclear Energy Agency, Pasar Jumat, South Jakarta and the Mechanical Test Laboratory of the Faculty of Engineering UHAMKA Pasar Rebo, East Jakarta. The data taken in this study is in the form of research data in the laboratory, namely data on changes in mechanical properties before and after irradiation, as well as data on the success of mechanical properties after a storage period of 1-5 weeks at room temperature.

The study was conducted on four types of HDPE packaging plastic brands A, B, C and D. Both of these plastics were cut with dumbbell cut / print blades in parallel cutting directions. After that the thickness was measured using a micrometer, then testing the breakout extension, tensile strength and yield strength using a Strograph R-1 test equipment to determine the initial mechanical properties of the sample.

Samples of samples that have not been tested, then irradiated with Co-60 gamma rays at doses of 10, 15, 20, 25 and 30 kGy at a dose rate of 6 kGy / hour. The irradiated sample is partially tested immediately and partially stored at room temperature. Tests for break extension, tensile strength and yield strength were carried out to determine changes in mechanical properties. Testing the mechanical properties of the stored samples was carried out after 1-5 weeks of storage.

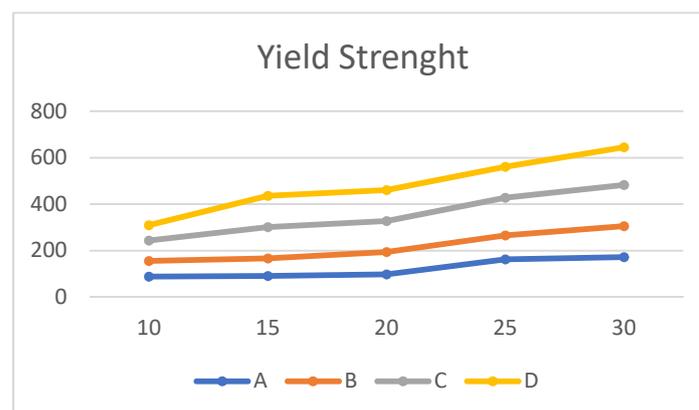
### 3. Results and discussion

To determine the initial mechanical properties of HDPE packaging plastic before storage, mechanical properties were tested which included elongation of break ( $E_b$ ), tensile strength ( $T_s$ ), and yield strength ( $Y_s$ ). The measurement results of the initial initial mechanical properties can be seen in table 1.

**Table 1.** Yield strength ( $Y_s$ ) at 0 weeks storage

Dosis Radiasi (kGy)	$Y_s \pm \Delta Y_s$ (kg/cm <sup>2</sup> )			
	A	B	C	D
10	88,89 ± 5,24	66,67 ± 4,29	88 ± 5,24	66,67 ± 4,29
15	91,67 ± 8,33	74,89 ± 3,74	135,39 ± 21,36	74,89 ± 3,74
20	98,07 ± 5,28	95,78 ± 17,72	133,58 ± 15,82	133,58 ± 15,82
25	162,96 ± 37,77	102,55 ± 11,86	162,96 ± 37,77	133,58 ± 15,82
30	172,00 ± 8,69	133,58 ± 15,82	177,33 ± 10,11	162,96 ± 37,77

From table 1 it can be seen that gamma irradiation causes the yield strength ( $Y_s$ ) in HDPE packaging plastic brands A, B, C and D to increase from a dose of 10 kGy (before irradiation) to a dose of 15 kGy, as much as 3.13% in type A and 12, 33% on type D, Increased yield strength continues until the dose of 25 kGy in both plastics. The biggest increase in brand A occurred from doses 10 to 15 kGy, as much as 66.17% and from doses 15 to 20 kGy as much as 30.25% for brands D.



**Figure 1.** Strength of Yield ( $Y_s$ ) vs. Radiation Dosage (kGy) at 0 Week of Storage

Figure 1 shows the yield strength ( $Y_s$ ) increasing with increasing radiation dose. The increase in yield strength is due to the occurrence of free radical reactions that form cross-linked tissue between plastic molecules as described above. The greater the irradiation dose given, the more crosslinked plastic molecule chains are produced, the more difficult the plastic to stretch because the force required is greater, so the yield strength increases

**Table 2.** Measurement of average tensile strength (Ts) during 0 weeks of storage

Dosis Radiasi (kGy)	Ts $\pm$ $\Delta T_s$ (kg/cm <sup>2</sup> )			
	A	B	C	D
10	(235.56 $\pm$ 34.11)	(78.26 $\pm$ 7.54)	(233.58 $\pm$ 38.74)	(78.28 $\pm$ 7.54)
15	(253.33 $\pm$ 18.26)	(95.33 $\pm$ 10.73)	(235.56 $\pm$ 34.11)	(95.33 $\pm$ 10.73)
20	(266.07 $\pm$ 25.25)	(147.88 $\pm$ 59.72)	(255.67 $\pm$ 12.90)	(233.58 $\pm$ 38.74)
25	(318.50 $\pm$ 26.71)	(186.42 $\pm$ 29.18)	(318.52 $\pm$ 26.71)	(234.58 $\pm$ 38.73)
30	(354.67 $\pm$ 15.20)	(233.58 $\pm$ 38.74)	(388.00 $\pm$ 9.84)	(318.52 $\pm$ 26.71)

From table 2, it is seen that gamma irradiation causes tensile strength (Ts) in brand A-D HDPE packaging plastic to increase with increasing radiation dose to a dose of 25 kGy. The optimum increase occurs from the dose of 10 to 15 kGy, which is equal to 19.73%.

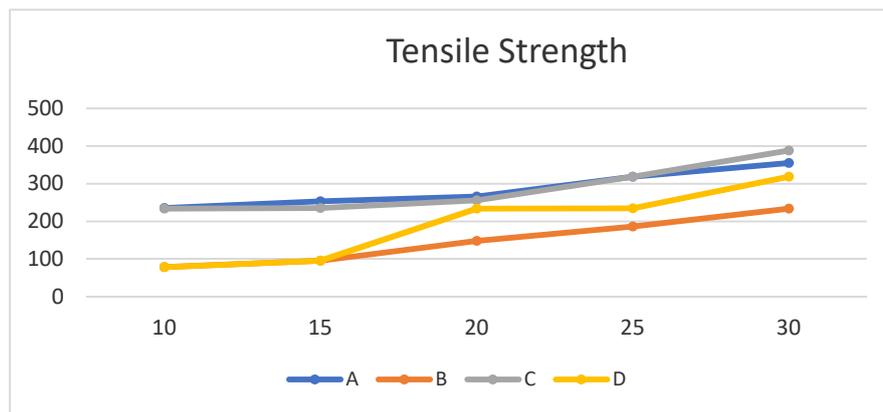
**Figure 2.** Tensile Strength (Ts) vs. Radiation Dosage (kGy) at 0 Week Storage

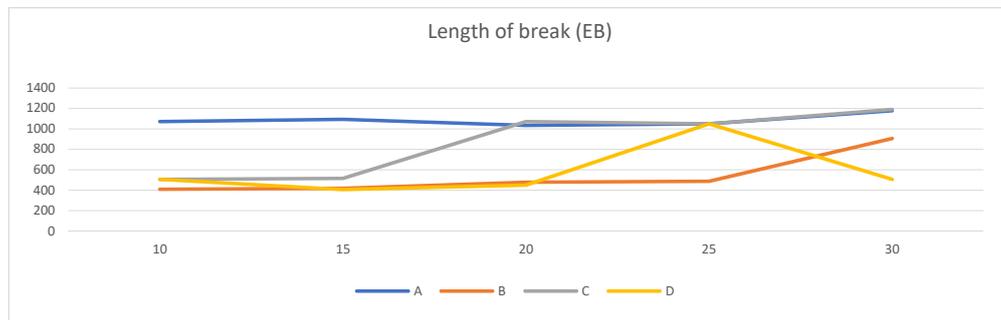
Figure 2 shows an increase in tensile strength (Eb) in each addition of irradiation doses. The increase is also caused by the occurrence of free radical reactions that form cross-linked tissue between plastic molecules. The greater the irradiation dose given, the more crosslinked plastic molecule chains are produced, the more difficult the plastic to stretch because the force needed to break up is getting bigger, so the tensile strength of HDPE plastic is increasing.

**Table 3.** Measure the average length of break (Eb) when 0 weeks of storage

Dosis Radiasi (kGy)	Eb $\pm$ $\Delta E_b$ (%)			
	A	B	C	D
10	(1070.00 $\pm$ 71.76)	(408.00 $\pm$ 31.14)	(504.00 $\pm$ 58.99)	(504.00 $\pm$ 58.99)
15	(1092.00 $\pm$ 50.20)	(448.00 $\pm$ 20.49)	(516.00 $\pm$ 26.08)	(404.00 $\pm$ 12.82)
20	(1034.00 $\pm$ 85.62)	(476.00 $\pm$ 34.35)	(1070.00 $\pm$ 71.76)	(448.00 $\pm$ 20.76)

25	(1050.00 ± 24.49)	(486.00 ± 57.27)	(1050.00 ± 24.49)	(1050.00 ± 24.49)
30	(1176.00 ± 28.81)	(504.00 ± 58.99)	(1188.00 ± 19.24)	(1050.00 ± 24.49)

From table 3, it can be seen that gamma irradiation causes the breakout extension (Eb) on brand A HDPE packaging plastic to increase from 0 to 5 kGy, then decrease by 5.31% at a dose of 10 kGy and then continue to increase to a dose of 25 kGy. The optimum increase occurred from doses 15 to 20 kGy, as much as 12.00%. For plastic B, the breakout extension (Eb) continues to increase with increasing irradiation doses up to 25 kGy. The optimum Eb increase occurs from a dose of 0 to 5 kGy, at 9.80%.



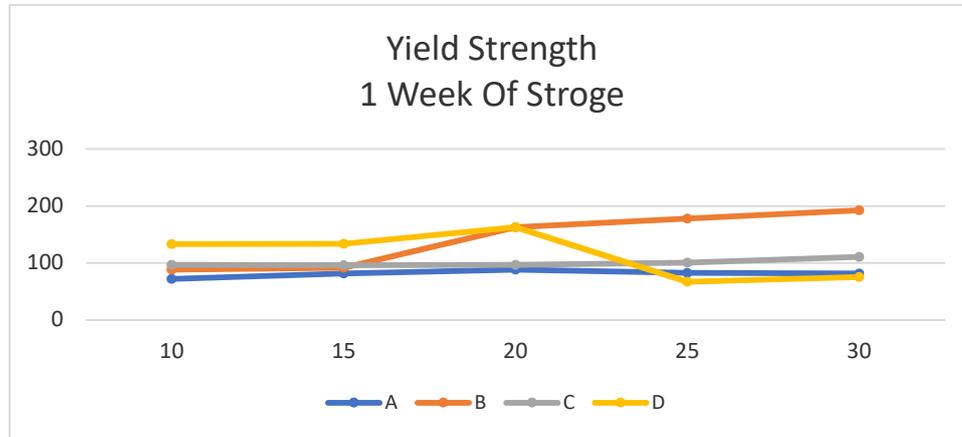
In figure 3, an extension of the break (Eb) on both HDPE packaging plastics is increased as the radiation dose increases. This increase is also caused by cross-linking in more HDPE molecular chains, making it difficult to stretch. In plastic A there was a decrease in Eb from a dose of 5 kGy to a dose of 10 kGy of 5.31%. This might be due to parallax errors because the measurement of the breakout extension is done manually, that is by using the bar.

**Table 4.** Measuring average yield strength (Ys) at 1 week of storage

Dosis Radiasi (kGy)	Ys ± ΔYs (kg/cm <sup>2</sup> )			
	A	B	C	D
10	(72.00 ± 2.98)	(88.00 ± 5.24)	(92.61 ± 8.93)	(133.58 ± 15.83)
15	(81.33 ± 2.98)	(91.67 ± 6.24)	(95.64 ± 10.55)	(133.58 ± 15.73)
20	(88.00 ± 2.98)	(162.96 ± 37.77)	(96.73 ± 5.78)	(162.92 ± 37.77)
25	(82.67 ± 3.65)	(177.33 ± 10.11)	(100.24 ± 6.72)	(66.67 ± 4.29)
30	(81.33 ± 2.98)	(172.00 ± 8.69)	(110.67 ± 8.94)	(74.89 ± 3.74)

Table 4 shows the changes in the second yield strength of HDPE packaging plastic which had been stored one week after irradiation. Plastic A showed a yield strength increased from a dose of 5 kGy to 15 kGy, then continued to decrease to a dose of 25 kGy. Plastic B shows that the yield strength

continues to increase in each dose addition and optimum at a dose of 25 kGy, as well as C plastic, while the D plastic decreases continuously.



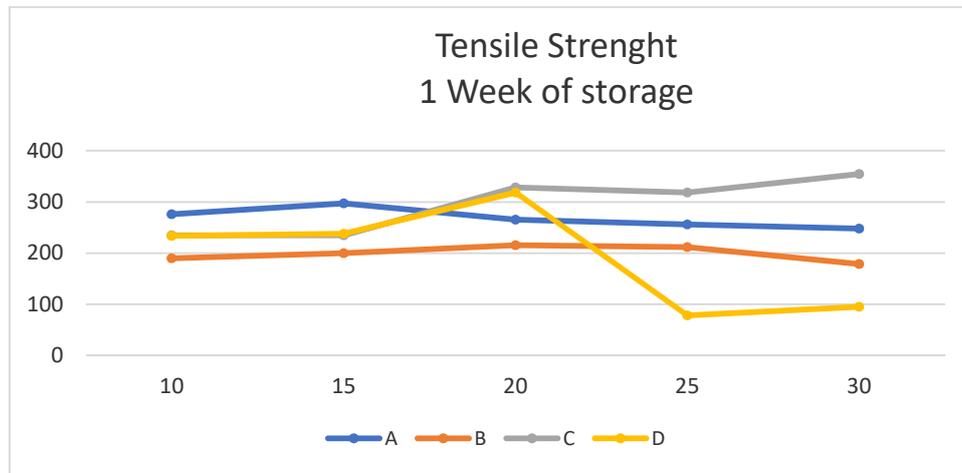
**Figure 4.** Strength of Yield (Ys) vs. Radiation Dosage (kGy) at 1 Storage Week

From figure 4, it can be seen that there is a slight decrease in yield strength in plastic A compared to before storage. This shows that after one week's irradiation A plastic still has good yield strength. Plastic B showed an increase in yield strength at doses 5 and 10 kGy compared to before storage, then at doses of 15-25 kGy there was a decrease in yield strength compared to before storage. This decrease is thought to be caused by a cross-link that is easily separated, as well as C and D.

**Table 5.** Measurement of average tensile strength (Ts) at 1 week of storage

Dosis Radiasi (kGy)	Ts ± ΔTs (kg/cm <sup>2</sup> )			
	A	B	C	D
10	(276.00 ± 7.60)	(189.94 ± 17.09)	(235.00 ± 34.11)	(233.58 ± 38.74)
15	(297.33 ± 10.11)	(200.24 ± 9.01)	(235.00 ± 34.11)	(238.00 ± 34.11)
20	(265.33 ± 17.89)	(215.52 ± 7.59)	(328.67 ± 9.98)	(318.52 ± 26.70)
25	(256.00 ± 7.60)	(212.00 ± 16.06)	(318.52 ± 26.72)	(78.28 ± 7.54)
30	(248.00 ± 20.76)	(178.79 ± 18.12)	(354.67 ± 15.20)	(95.33 ± 10.73)

Table 5 shows that after being stored for one week in plastic A there was an increase in tensile strength of 7.73% from dose 5 to 10 kGy, then continued to decline 19.89% to a dose of 25 kGy. In B plastic there was an increase in tensile strength of 13.47% from doses of 5 to 15 kGy, then decreased by 17.04% to a dose of 25 kGy.



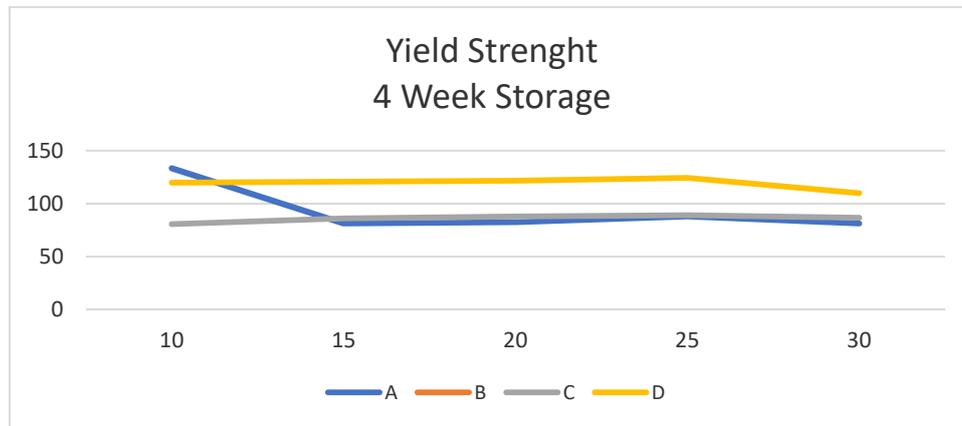
**Figure 5.** Tensile Strength (Ts) vs. Radiation Dosage (kGy) at 1 Storage Week

From figure 5, it can be seen in plastic A, there was a slight increase in tensile strength at a dose of 5-10 kGy compared to before storage. Then from doses of 15-25 kGy there is a decrease compared to before storage. This shows that after one week's irradiation A plastic still has good tensile strength. Plastic D shows an increase in tensile strength of doses 5 and 15 kGy compared to before storage, then at doses of 20-25 kGy a decrease in tensile strength compared to before storage. This decrease is also thought to be caused by a cross-link that is easily separated, so the force needed to pull the plastic down decreases.

**Table 6.** Measurement of average yield strength (Ys) at 4 weeks of storage

Dosis Radiasi (kGy)	Ys ± ΔYs (kg/cm <sup>2</sup> )			
	A	B	C	D
10	(133.58 ± 15.86)	(80.85 ± 5.41)	(80.85 ± 5.41)	(120.00 ± 6.67)
15	(81.33 ± 2.98)	(86.30 ± 4.78)	(86.31 ± 4.78)	(120.97 ± 12.13)
20	(82.67 ± 3.65)	(88.00 ± 2.98)	(88.00 ± 2.98)	(121.82 ± 9.01)
25	(88.00 ± 24.67)	(89.33 ± 3.65)	(89.33 ± 3.65)	(124.48 ± 5.58)
30	(81.33 ± 2.88)	(86.67 ± 4.71)	(86.67 ± 4.71)	(110.06 ± 9.90)

Table 6 shows the measurement of the average second yield strength of HDPE packaging plastic after being stored 4 weeks after irradiation. Both plastics had increased yield strength to a dose of 20 kGy, then subsequently continued to decrease to a dose of 25 kGy.



**Figure 6.** Strength of Yield (Ys) vs. Radiation Dosage (kGy) at 4 weeks of storage

Figure 6 shows that in all four plastics that have been stored for four weeks there is an increase in tensile strength compared to those stored for one week. It shows that after four weeks of storage the HDPE irradiation packaging plastic has good yield strength.

**Table 7.** Measurement of average tensile strength (Ts) at 4 weeks of storage

Dosis Radiasi (kGy)	Ts ± ΔTs (kg/cm <sup>2</sup> )			
	A	B	C	D
10	(278.67 ± 17.54)	(280.67 ± 17.54)	(233.58 ± 38.74)	(205.33 ± 7.30)
15	(294.9 ± 27.60)	(296.91 ± 27.60)	(276.00 ± 7.6)	(219.03 ± 32.61)
20	(300.00 ± 10.95)	(304.00 ± 9.43)	(297.00 ± 10.11)	(230.55 ± 22.44)
25	(305.33 ± 9.89)	(305.33 ± 9.43)	(265.33 ± 17.89)	(226.55 ± 19.22)
30	(290.67 ± 14.61)	(292.67 ± 14.61)	(256.00 ± 7.6)	(203.88 ± 14.58)

Table 7 shows the tensile strength of plastic A increasing and most at a dose of 20 kGy, then decreasing 4.80% at a dose of 25 kGy. In plastic B the greatest tensile strength at a dose of 15 kGy, then continues to decrease 11.57% to a dose of 25 kGy plastic C and continues to decrease in the plastic D.



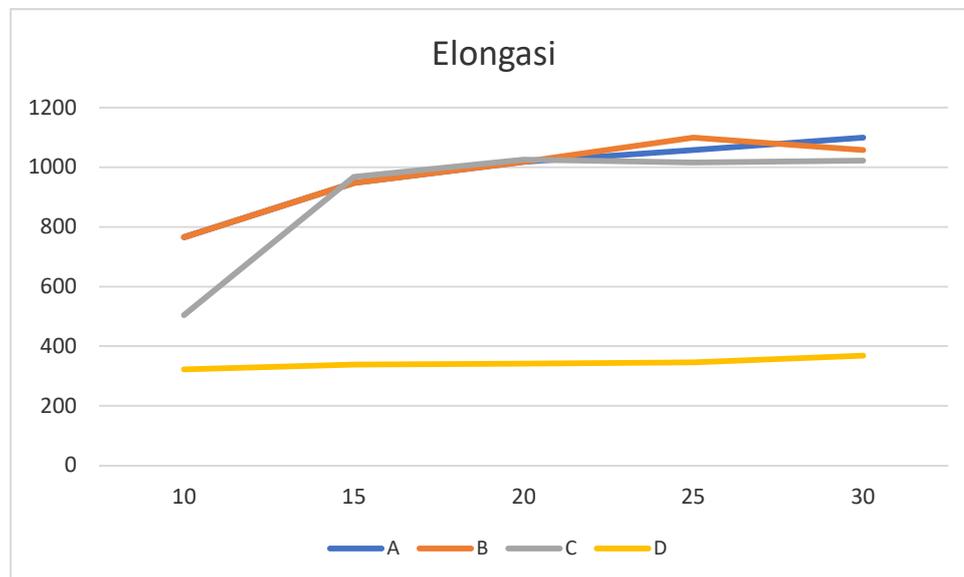
**Figure 7.** Tensile Strength (Ts) vs. Radiation Dosage (kGy) for 4 Storage Weeks

The graph above shows the tensile strength of the four HDPE plastics stored four weeks increased than those stored one week. This shows that after four weeks of storage, the irradiated HDPE packaging plastic has good tensile strength. The increase in tensile strength may be due to the remaining free radical species, so the crosslinking of molecules is still strong.

**Table 8.** Measurement of the average length of break ( $E_b$ ) at 4 weeks of storage

Dosis Radiasi (kGy)	$E_b \pm \Delta E_b$ (%)			
	A	B	C	D
10	(766.00 ± 38.47)	(765.16 ± 17.54)	(504.00 ± 58.54)	(322.00 ± 16.43)
15	(948.00 ± 10.95)	(948.01 ± 27.60)	(968.01 ± 27.75)	(338.00 ± 21.68)
20	(1018.00 ± 39.62)	(1018.00 ± 9.43)	(1026.00 ± 32.43)	(342.00 ± 10.95)
25	(1058.00 ± 16.43)	(1100.00 ± 9.43)	(1016.00 ± 278.02)	(346.00 ± 25.10)
30	(1100.00 ± 38.08)	(1058.00 ± 14.61)	(1022.00 ± 34.21)	(368.00 ± 34.21)

Plastic A the greatest increase occurred at a dose of 10 kGy, which increased by 23.76% from the dose of 5 kGy. In B plastic the greatest increase occurred at a dose of 25 kGy, which increased by 6.36% from a dose of 20 kGy, then decreased in C and D.



**Figure 8.** Elongasi ( $E_b$ ) vs. Radiation Dosage (kGy) for 4 Storage Weeks

Figure 8 shows the breakdown of A plastic after being stored for four weeks has decreased slightly compared to that stored for one week. The decrease is probably due to the crossing of the weakened plastic molecules, even though the extension of the break-up of plastic A is still good. Plastic D showed an increase in breaking length from a dose of 10-20 kGy, while at a dose of 25 kGy it decreased compared to that stored for one week. This may be caused by crosslinking at a dose of 25 kGy weakening and also due to a parallax error in measuring the breakout extension.

The limitation in this study was that it was unable to observe and explain how many types and types of free radicals were formed on HDPE packaging plastics, both those which were not stored and those stored after gamma irradiation. In theory, irradiated HDPE plastic after being stored for some time will experience mechanical properties. In this study, after it was stored there was a decrease in mechanical properties in the breakdown extension parameters, but the yield strength and tensile strength parameters showed an increase. In addition, this study also cannot show that any increase in radiation dose will result in an increase in the number of free radicals.

This might be explained if free radical testing is carried out. In addition, the observation of the effects of gamma radiation on HDPE plastic in this study is limited to the increase or decrease in mechanical properties, while observing the possible formation of chemical reactions between plastic and gamma rays, which will affect changes in the chemical elements of plastic or the security of usage has not been done. This is due to the limitations of theory and ability and there is no relevant research on this matter. Observation of what the maximum dose is suitable for the purpose of radiation has also not been done well.

However, I think the application of gamma irradiation techniques to HDPE plastic in this study does not affect the safety factor of packaging plastic consumption, assuming that plastic is widely used because it has an inert nature or is not easy to react with the packaged material. In addition, the irradiation process using gamma radiation is a "cold" process because it does not cause a rise in temperature in the material it passes. As a result, changes in chemical elements that occur due to radiation quantitatively are also less. In addition, the maximum radiation dose used in this study only reached 30 kGy, whereas in previous studies larger radiation doses were used.

#### 4. Conclusion

From the research that has been done, it was found that gamma irradiation caused an increase in the mechanical properties of HDPE packaging plastic. The parameters of the mechanical properties tested in this study included yield strength (Ys), tensile strength (Ts), and elongation (Eb). The three parameters have increased compared to before being irradiated, an increase occurs every time a radiation dose is added.

Increased mechanical properties are caused by the formation of free radicals in plastic when gamma irradiation. The free radical species formed cause the formation of cross bonds between plastic molecules, so that the yield strength, tensile strength, and elongation of the break will increase and the force required by the plastic to stretch and break will be greater. The greater the radiation dose given, the more crosslinking of the plastic molecules produced, the more difficult the plastic to stretch and the mechanical properties to increase.

Irradiated HDPE packaging plastic stored for a period of time can experience changes in mechanical properties. These changes can be in the form of increase or decrease in yield strength, tensile strength, and elongation at break. If there is a decrease in mechanical properties it is caused by crosslinking to a weakened plastic molecule. In this study, the reduction in mechanical properties of irradiated HDPE plastic after storage is relatively small, so it is still strong and can be used long enough.

The application of gamma irradiation must be carried out at the right dosage, so that it matches the purpose of irradiation. Gamma irradiation at the appropriate dosage will not affect the safety of use, because gamma irradiation does not cause a temperature increase in the material it passes. As a result, changes in chemical elements that occur due to radiation quantitatively are also less.

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Dr. Imas Ratna Ermawati, M.Pd  
- The effect of chemical  
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*by Dr. Imas Ratna Ermawati, M.pd Uploaded By Greycy*

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## The effect of chemical commitments with exposure to gamma irradiation dosage and save time on test attraction and pullet limits of HDPE pack

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## <sup>2</sup>The effect of chemical commitments with exposure to gamma irradiation dosage and save time on test attraction and pullet limits of HDPE pack

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**Abstract.** This study aims to determine the effect of gamma irradiation doses and time of storage on the mechanical properties of HDPE packaging plastics, and to apply gamma irradiation techniques to improve the mechanical quality of materials, especially plastic-based products. Packaging plastic is the most popular packaging material used, many businesses choose plastic as packaging for their products Research Place for Polymer laboratories, Isotopes and Radiation Technology Application Centers, National Nuclear Energy Agency, Pasar Jumat, South Jakarta and Mechanical Test Laboratory of the faculty of Engineering, UHAMKA Pasar Rebo<sup>12</sup> East Jakarta. To determine the resistance of packaging plastic to gamma irradiation, the effect of gamma irradiation dosage and storage time on the mechanical properties of HDPE plastic packaging were carried out. The research will be conducted with Cobalt-60 gamma radiation sources at irradiation doses of 10, 15, 20, 25, and 30 kGy with a dose rate of 6 kG<sup>18</sup> hour, then some irradiated plastic footage is stored at room temperature for 0 and 5 weeks. The mechanical properties tested were yield strength, tensile strength, and elongation at break using the strogaph R1 tensile test tool. Gamma irradiation caused yield strength, tensile strength and elongation in the A brand HDPE packaging plastic increased from 0 to 5 kGy, then decreased by 5.31% at a dose of 10 kGy and then continued to increase to a dose of 25 kGy. The optimum increase occurred from doses 15 to 20 kGy, as much as 12.00%. For plastic B, the breakout extension (Eb) continues to increase as the irradiation dose increases to 30 kGy. The optimum Eb increase occurs from a dose of 0 to 5 kGy, at 9.80%. Increased mechanical properties are caused by free radical species formed during the irradiation process, so that a cross-bond is formed between HDPE plastic packaging molecules. While the decrease occurs due to the weakening of the cross bond between the HDPE packaging plastic molecules.

### 1. Introduction

Packaging plastic is the most popular packaging material used. Many businesses choose plastic as packaging for their products. This is because plastic has superior properties such as strong but light, inert, not corroding, thermoplastic (soft when heated and hardened when cooled), and can be labeled or molded with various creations.

At this time, packaging plastic is widely used to meet various needs so that the plastic gets various treatments. In addition, there are also various types, shapes and thicknesses that are very diverse. Packaging plastic used with the intention of protecting, marking, improving the appearance<sup>3</sup> and wrapping of goods. The types of packaging plastic that are widely available on the market are in the



form of bag films, including raw materials from LDPE (Low Density Polyethylene), HDPE (High Density Polyethylene), PP (Polypropylene) and OPP (Oriented Polypropylene).

The four raw materials for making packaging plastic, they have various weaknesses and advantages, but the application depends on its basic properties so that it will affect its mechanical properties. HDPE (High Density Polyethylene) is a polyethylene with high density / density which is 941 - 965 kg / m<sup>3</sup>, as packaging material has a visually not clear (opaque) is rigid, less elastic but strong and heat resistant [1].

Research and development of HDPE experienced rapid progress, one of which was the application of irradiation techniques that could be used in packaging plastic. According to Winamo et al., (1980), irradiation is a technique of using energy to irradiate materials using artificial irradiation sources [2]. In general, irradiation techniques are the transmission of energy with radiation (for example gamma rays) of high intensity and do not make the material that receives radiation energy become radioactive.

Today, the application of radioisotope (gamma) utilization is increasingly developing in Indonesia and is widely used in various fields, such as agriculture, animal husbandry, medicine, industry, hydrology, and food [3]. Gamma irradiation of HDPE packaging plastic is one example of application in the industrial field. The application of high energy radiation to the synthesis and modification of polymers (plastics) is based on the fact that high energy radiation has the ability to produce free radicals that begin with chemical reactions [4].

Previous studies showed that gamma irradiation affected the mechanical properties of polyethylene and polypropylene based packaging plastic, namely increasing tensile strength and decreasing break elongation [5]. In the study also stated that packaging plastic that has been irradiated by gamma, then stored for a certain period of time undergoes changes in mechanical properties.

Based on this research, the effect of gamma irradiation dosage and the time saved on the mechanical properties of HDPE type plastic packaging was observed. Testing of mechanical properties include elongation break, tensile stress, and yield strength. In line with the increasing standard of living, there will also be an increase in demand for plastic-based materials. This requires the latest plastic processing technology in an effort to obtain goods of reliable quality.

This study measured the mechanical properties of HDPE packaging plastic before and after irradiation. Irradiation was carried out at radiation doses of 5, 10, 15, 20, and 25 kGy. Testing the mechanical properties of HDPE packaging plastic is carried out after storage within 1 and 2 consecutive weeks. The mechanical properties tested included tensile strength, yield strength, and elongation break. Plastics are part of hydrocarbon molecules which are the basic constituents of carbon and hydrogen. At present there are mainly six widely used polymer commodities, they are polyethylene, polypropylene, polyvinyl chloride, polyethylene terephthalate, polystyrene, and polycarbonate. They make up 98% of all polymers and plastics found in everyday life. Each of these polymers has degradation and heat, light and chemical properties.

Plastics are long-chain polymers from atoms that bind to one another. This chain forms many repetitive molecular units, or monomers. The main component of plastic before forming a polymer is a monomer, the shortest chain. Polymers are a combination of several monomers that will form a very long chain. If the same monomer is called homopolymer, and if the monomer is different it will produce a copolymer [6]. Materials made from plastic from oil and gas as a natural source, in its development are replaced by synthetic materials so that the desired properties of plastic can be obtained by copolymerization, lamination, and extrusion. When chains of plastic monomers are grouped together in a random pattern, resembling a haystack it is called amorphous, if it is organized almost parallel it is called crystalline with harder and harder properties. Classification of plastic according to its chemical structure is divided into two types, namely:

1. Linear, if a monomer forms a straight (linear) polymer chain, a thermoplastic plastic will form which has the property of melting at a certain temperature, adhering to changes in temperature and reversible to its nature, which is hardened again when cooled.

2. Three-dimensional network, if the three-dimensional monomers are due to chain polymerization, thermosetting plastic will be formed with properties irreversible. If once hardening has occurred, the material cannot be softened again [7].

Thermoplastics are plastic that can be softened repeatedly using heat, including polyethylene, polypropylene, polystyrene and polyvinylchloride. The best thermoplastic plastic for packaging is that has a freezing point below 00C, a melting temperature above 1000C. [8] While thermosets are plastic that cannot be softened by heating, including bakelit, phenol formaldehyde and urea formaldehyde. Thermosetting plastics are usually hard because they have cross bonds. Thermoset plastic becomes harder when heated because the heat causes cross bonds to form more easily. Thermoset type plastic is not very attractive in the recycling process because in addition to difficult handling, the volume is far less (around 10%) than the volume of thermoplastic plastic types [9].

Material mechanical properties, is one of the most important factors underlying the selection of materials in a design. Mechanical properties can be interpreted as a response or material behavior to the given load, either in the form of force, torque or a combination of both [10]. In practice loading on materials is divided into two, namely static load and dynamic load. The difference between the two is only in the time function where the static load is not affected by the time function while the dynamic load is influenced by the time function.

Radiation is a general term for all types of energy emitted without media. Radiation is the emission of energy through matter or space in the form of heat, particles or electromagnetic / light waves (photons) from the radiation source. There are several radiation sources that we know around our lives, for example television, lighting, food heaters (microwaves), computers, and so on. Irradiation is a physical process that can be used to improve the quality of a material. The type of radiation used is high-energy radiation called ionizing radiation, because it causes ionization in the material it passes.

According to Winamo et al. , irradiation is a technique of using energy to irradiate materials using artificial irradiation sources. According to Ivanov, gamma ray irradiation is a beam of high-energy electromagnetic waves in the form of energy packs (photons) [11]. In general, irradiation techniques are the transmission of energy with radiation (eg gamma rays) of high intensity and not making the material that receives radiation energy become radioactive.

## 20 2. Research methods

The methodology used in conducting this research is the experimental method used to prove the truth of the hypothesis through experiments carried out in polymer laboratories, Isotopes and Radiation Technology Application Centers, National Nuclear Energy Agency, Pasar Jumat, South Jakarta and the Mechanical Test Laboratory of the Faculty of Engineering UHAMKA Pasar Rebo, East Jakarta. The data taken in this study is in the form of research data in the laboratory, namely data on changes in mechanical properties before and after irradiation, as well as data on the success of mechanical properties after a storage period of 1-5 weeks at room temperature.

The study was conducted on four types of HDPE packaging plastic brands A, B, C and D. Both of these plastics were cut with dumbbell cut / print blades in parallel cutting directions. After that the thickness was measured using a micrometer, then testing the breakout extension, tensile strength and yield strength using a Strogaph R-1 test equipment to determine the initial mechanical properties of the sample.

Samples of samples that have not been tested, then irradiated with Co-60 gamma rays at doses of 10, 15, 20, 25 and 30 kGy at a dose rate of 6 kGy / hour. The irradiated sample is partially tested immediately and partially stored at room temperature. Tests for break extension, tensile strength and yield strength were carried out to determine changes in mechanical properties. Testing the mechanical properties of the stored samples was carried out after 1-5 weeks of storage.

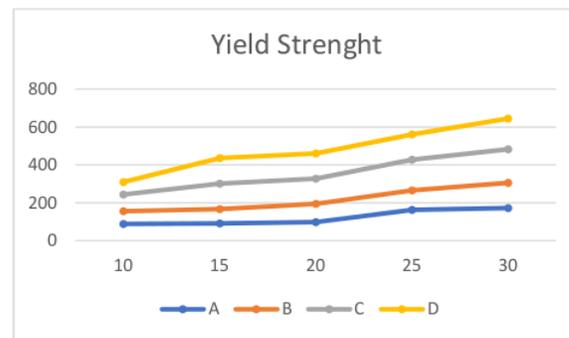
### 3. Results and discussion

To determine the initial mechanical properties of HDPE packaging plastic before storage, mechanical properties were tested which included elongation of break ( $E_b$ ), tensile strength ( $T_s$ ), and yield strength ( $Y_s$ ). The measurement results of the initial initial mechanical properties can be seen in table 1.

**Table 1.** Yield strength ( $Y_s$ ) at 0 weeks storage

Dosis Radiasi (kGy)	$Y_s \pm \Delta Y_s (\text{kg/cm}^2)$			
	A	B	C	D
10	$88,89 \pm 5,24$	$66,67 \pm 4,29$	$88 \pm 5,24$	$66,67 \pm 4,29$
15	$91,67 \pm 8,33$	$74,89 \pm 3,74$	$135,39 \pm 21,36$	$74,89 \pm 3,74$
20	$98,07 \pm 5,28$	$95,78 \pm 17,72$	$133,58 \pm 15,82$	$133,58 \pm 15,82$
25	$162,96 \pm 37,77$	$102,55 \pm 11,86$	$162,96 \pm 37,77$	$133,58 \pm 15,82$
30	$172,00 \pm 8,69$	$133,58 \pm 15,82$	$177,33 \pm 10,11$	$162,96 \pm 37,77$

From table 1 it can be seen that gamma irradiation causes the yield strength ( $Y_s$ ) in HDPE packaging plastic brands A, B, C and D to increase from a dose of 10 kGy (before irradiation) to a dose of 15 kGy, as much as 3.13% in type A and 12, 33% on type D, Increased yield strength continues until the dose of 25 kGy in both plastics. The biggest increase in brand A occurred from doses 10 to 15 kGy, as much as 66.17% and from doses 15 to 20 kGy as much as 30.25% for brands D.



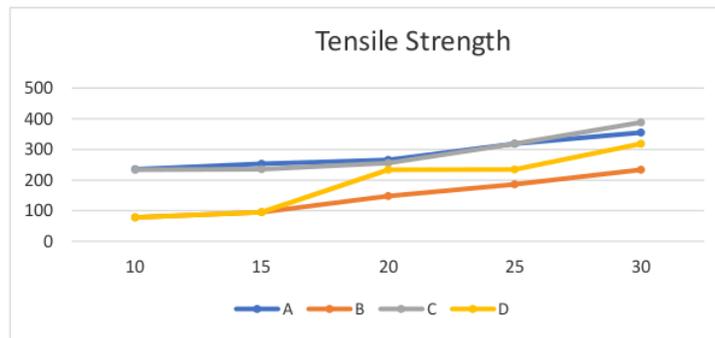
**Figure 1.** Strength of Yield ( $Y_s$ ) vs. Radiation Dosage (kGy) at 0 Week of Storage

Figure 1 shows the yield strength ( $Y_s$ ) increasing with increasing radiation dose. The increase in yield strength is due to the occurrence of free radical reactions that form cross-linked tissue between plastic molecules as described above. The greater the irradiation dose given, the more crosslinked plastic molecule chains are produced, the more difficult the plastic to stretch because the force required is greater, so the yield strength increases

**Table 2.** Measurement of average tensile strength (Ts) during 0 weeks of storage

Dosis Radiasi (kGy)	Ts ± ΔTs (kg/cm <sup>2</sup> )			
	A	B	C	D
10	(235.56 ± 34.11)	(78.26 ± 7.54)	(233.58 ± 38.74)	(78.28 ± 7.54)
15	(253.33 ± 18.26)	(95.33 ± 10.73)	(235.56 ± 34.11)	(95.33 ± 10.73)
20	(266.07 ± 25.25)	(147.88 ± 59.72)	(255.67 ± 12.90)	(233.58 ± 38.74)
25	(318.50 ± 26.71)	(186.42 ± 29.18)	(318.52 ± 26.71)	(234.58 ± 38.73)
30	(354.67 ± 15.20)	(233.58 ± 38.74)	(388.00 ± 9.84)	(318.52 ± 26.71)

From table 2, it is seen that gamma irradiation causes tensile strength (Ts) in brand A-D HDPE packaging plastic to increase with increasing radiation dose to a dose of 25 kGy. The optimum increase occurs from the dose of 10 to 15 kGy, which is equal to 19.73%.



**Figure 2.** Tensile Strength (Ts) vs. Radiation Dosage (kGy) at 0 Week Storage

Figure 2 shows an increase in tensile strength (Eb) in each addition of irradiation doses. The increase is also caused by the occurrence of free radical reactions that form cross-linked tissue between plastic molecules. The greater the irradiation dose given, the more crosslinked plastic molecule chains are produced, the more difficult the plastic to stretch because the force needed to break up is getting bigger, so the tensile strength of HDPE plastic is increasing.

**Table 3.** Measure the average length of break (Eb) when 0 weeks of storage

Dosis Radiasi (kGy)	Eb ± ΔEb (%)			
	A	B	C	D
10	(1070.00 ± 71.76)	(408.00 ± 31.14)	(504.00 ± 58.99)	(504.00 ± 58.99)
15	(1092.00 ± 50.20)	(448.00 ± 20.49)	(516.00 ± 26.08)	(404.00 ± 12.82)
20	(1034.00 ± 85.62)	(476.00 ± 34.35)	(1070.00 ± 71.76)	(448.00 ± 20.76)

25	(1050.00 ± 24.49)	(486.00 ± 57.27)	(1050.00 ± 24.49)	(1050.00 ± 24.49)
30	(1176.00 ± 28.81)	(504.00 ± 58.99)	(1188.00 ± 19.24)	(1050.00 ± 24.49)

From table 3, it can be seen that gamma irradiation causes the breakout extension (Eb) on brand A HDPE packaging plastic to increase from 0 to 5 kGy, then decrease by 5.31% at a dose of 10 kGy and then continue to increase to a dose of 25 kGy. The optimum increase occurred from doses 15 to 20 kGy, as much as 12.00%. For plastic B, the breakout extension (Eb) continues to increase with increasing irradiation doses up to 25 kGy. The optimum Eb increase occurs from a dose of 0 to 5 kGy, at 9.80%.



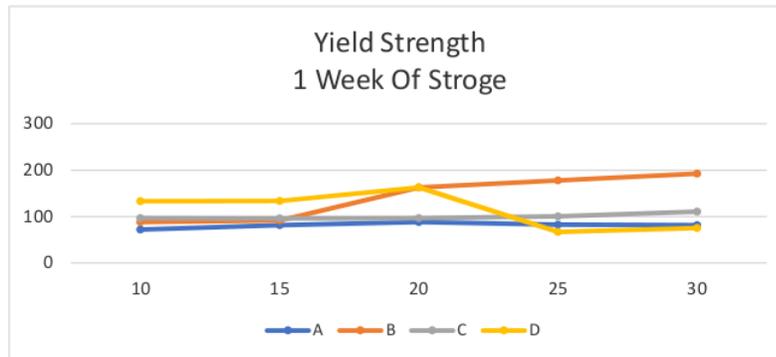
In figure 3, an extension of the break (Eb) on both HDPE packaging plastics is increased as the radiation dose increases. This increase is also caused by cross-linking in more HDPE molecular chains, making it difficult to stretch. In plastic A there was a decrease in Eb from a dose of 5 kGy to a dose of 10 kGy of 5.31%. This might be due to parallax errors because the measurement of the breakout extension is done manually, that is by using the bar.

**Table 4.** Measuring average yield strength (Ys) at 1 week of storage

Dosis Radiasi (kGy)	Ys ± ΔYs (kg/cm <sup>2</sup> )			
	A	B	C	D
10	(72.00 ± 2.98)	(88.00 ± 5.24)	(92.61 ± 8.93)	(133.58 ± 15.83)
15	(81.33 ± 2.98)	(91.67 ± 6.24)	(95.64 ± 10.55)	(133.58 ± 15.73)
20	(88.00 ± 2.98)	(162.96 ± 37.77)	(96.73 ± 5.78)	(162.92 ± 37.77)
25	(82.67 ± 3.65)	(177.33 ± 10.11)	(100.24 ± 6.72)	(66.67 ± 4.29)
30	(81.33 ± 2.98)	(172.00 ± 8.69)	(110.67 ± 8.94)	(74.89 ± 3.74)

Table 4 shows the changes in the second yield strength of HDPE packaging plastic which had been stored one week after irradiation. Plastic A showed a yield strength increased from a dose of 5 kGy to 15 kGy, then continued to decrease to a dose of 25 kGy. Plastic B shows that the yield strength

continues to increase in each dose addition and optimum at a dose of 25 kGy, as well as C plastic, while the D plastic decreases continuously.



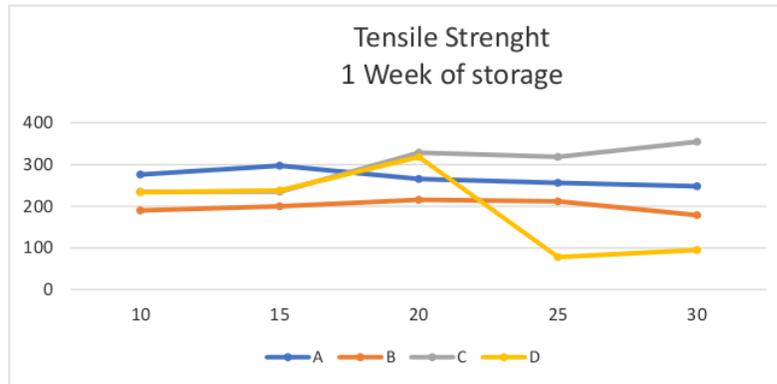
**Figure 4.** Strength of Yield (Ys) vs. Radiation Dosage (kGy) at 1 Storage Week

From figure 4, it can be seen that there is a slight decrease in yield strength in plastic A compared to before storage. This shows that after one week's irradiation A plastic still has good yield strength. Plastic B showed an increase in yield strength at doses 5 and 10 kGy compared to before storage, then at doses of 15-25 kGy there was a decrease in yield strength compared to before storage. This decrease is thought to be caused by a cross-link that is easily separated, as well as C and D.

**Table 5.** Measurement of average tensile strength (Ts) at 1 week of storage

Dosis Radiasi (kGy)	Ts ± ΔTs (kg/cm <sup>2</sup> )			
	A	B	C	D
10	(276.00 ± 7.60)	(189.94 ± 17.09)	(235.00 ± 34.11)	(233.58 ± 38.74)
15	(297.33 ± 10.11)	(200.24 ± 9.01)	(235.00 ± 34.11)	(238.00 ± 34.11)
20	(265.33 ± 17.89)	(215.52 ± 7.59)	(328.67 ± 9.98)	(318.52 ± 26.70)
25	(256.00 ± 7.60)	(212.00 ± 16.06)	(318.52 ± 26.72)	(78.28 ± 7.54)
30	(248.00 ± 20.76)	(178.79 ± 18.12)	(354.67 ± 15.20)	(95.33 ± 10.73)

Table 5 shows that after being stored for one week in plastic A there was an increase in tensile strength of 7.73% from dose 5 to 10 kGy, then continued to decline 19.89% to a dose of 25 kGy. In B plastic there was an increase in tensile strength of 13.47% from doses of 5 to 15 kGy, then decreased by 17.04% to a dose of 25 kGy.



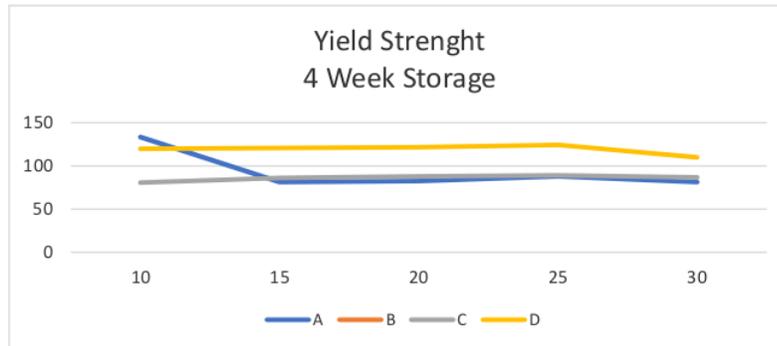
**Figure 5.** Tensile Strength (Ts) vs. Radiation Dosage (kGy) at 1 Storage Week

From figure 5, it can be seen in plastic A, there was a slight increase in tensile strength at a dose of 5-10 kGy compared to before storage. Then from doses of 15-25 kGy there is a decrease compared to before storage. This shows that after one week's irradiation A plastic still has good tensile strength. Plastic D shows an increase in tensile strength of doses 5 and 15 kGy compared to before storage, then at doses of 20-25 kGy a decrease in tensile strength compared to before storage. This decrease is also thought to be caused by a cross-link that is easily separated, so the force needed to pull the plastic down decreases.

**Table 6.** Measurement of average yield strength (Ys) at 4 weeks of storage

Dosis Radiasi (kGy)	Ys ± ΔYs (kg/cm <sup>2</sup> )			
	A	B	C	D
10	(133.58 ± 15.86)	(80.85 ± 5.41)	(80.85 ± 5.41)	(120.00 ± 6.67)
15	(81.33 ± 2.98)	(86.30 ± 4.78)	(86.31 ± 4.78)	(120.97 ± 12.13)
20	(82.67 ± 3.65)	(88.00 ± 2.98)	(88.00 ± 2.98)	(121.82 ± 9.01)
25	(88.00 ± 24.67)	(89.33 ± 3.65)	(89.33 ± 3.65)	(124.48 ± 5.58)
30	(81.33 ± 2.88)	(86.67 ± 4.71)	(86.67 ± 4.71)	(110.06 ± 9.90)

Table 6 shows the measurement of the average second yield strength of HDPE packaging plastic after being stored 4 weeks after irradiation. Both plastics had increased yield strength to a dose of 20 kGy, then subsequently continued to decrease to a dose of 25 kGy.



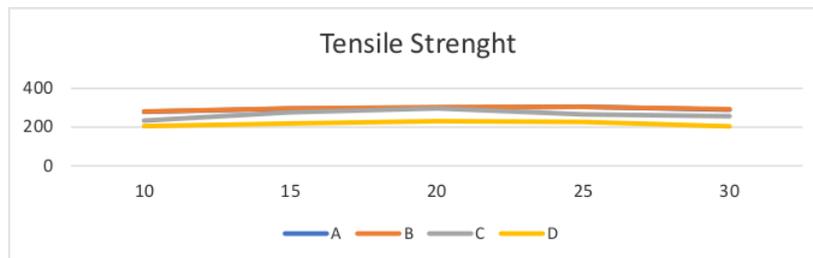
**Figure 6.** Strength of Yield ( $Y_s$ ) vs. Radiation Dosage (kGy) at 4 weeks of storage

Figure 6 shows that in all four plastics that have been stored for four weeks there is an increase in tensile strength compared to those stored for one week. It shows that after four weeks of storage the HDPE irradiation packaging plastic has good yield strength.

**Table 7.** Measurement of average tensile strength ( $T_s$ ) at 4 weeks of storage

Dosis Radiasi (kGy)	$T_s \pm \Delta T_s$ (kg/cm <sup>2</sup> )			
	A	B	C	D
10	(278.67 ± 17.54)	(280.67 ± 17.54)	(233.58 ± 38.74)	(205.33 ± 7.30)
15	(294.9 ± 27.60)	(296.91 ± 27.60)	(276.00 ± 7.6)	(219.03 ± 32.61)
20	(300.00 ± 10.95)	(304.00 ± 9.43)	(297.00 ± 10.11)	(230.55 ± 22.44)
25	(305.33 ± 9.89)	(305.33 ± 9.43)	(265.33 ± 17.89)	(226.55 ± 19.22)
30	(290.67 ± 14.61)	(292.67 ± 14.61)	(256.00 ± 7.6)	(203.88 ± 14.58)

Table 7 shows the tensile strength of plastic A increasing and most at a dose of 20 kGy, then decreasing 4.80% at a dose of 25 kGy. In plastic B the greatest tensile strength at a dose of 15 kGy, then continues to decrease 11.57% to a dose of 25 kGy plastic C and continues to decrease in the plastic D.



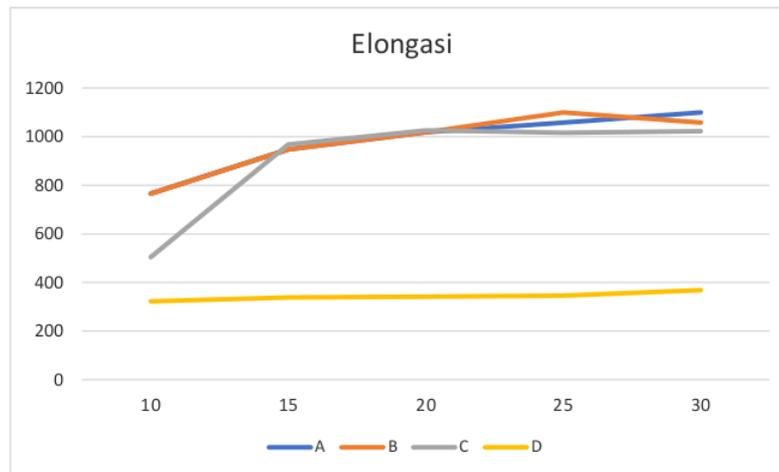
**Figure 7.** Tensile Strength ( $T_s$ ) vs. Radiation Dosage (kGy) for 4 Storage Weeks

The graph above shows the tensile strength of the four HDPE plastics stored four weeks increased than those stored one week. This shows that after four weeks of storage, the irradiated HDPE packaging plastic has good tensile strength. The increase in tensile strength may be due to the remaining free radical species, so the crosslinking of molecules is still strong.

**Table 8.** Measurement of the average length of break ( $E_b$ ) at 4 weeks of storage

Dosis Radiasi (kGy)	$E_b \pm \Delta E_b$ (%)			
	A	B	C	D
10	(766.00 ± 38.47)	(765.16 ± 17.54)	(504.00 ± 58.54)	(322.00 ± 16.43)
15	(948.00 ± 10.95)	(948.01 ± 27.60)	(968.01 ± 27.75)	(338.00 ± 21.68)
20	(1018.00 ± 39.62)	(1018.00 ± 9.43)	(1026.00 ± 32.43)	(342.00 ± 10.95)
25	(1058.00 ± 16.43)	(1100.00 ± 9.43)	(1016.00 ± 278.02)	(346.00 ± 25.10)
30	(1100.00 ± 38.08)	(1058.00 ± 14.61)	(1022.00 ± 34.21)	(368.00 ± 34.21)

Plastic A the greatest increase occurred at a dose of 10 kGy, which increased by 23.76% from the dose of 5 kGy. In B plastic the greatest increase occurred at a dose of 25 kGy, which increased by 6.36% from a dose of 20 kGy, then decreased in C and D.



**Figure 8.** Elongasi ( $E_b$ ) vs. Radiation Dosage (kGy) for 4 Storage Weeks

Figure 8 shows the breakdown of A plastic after being stored for four weeks has decreased slightly compared to that stored for one week. The decrease is probably due to the crossing of the weakened plastic molecules, even though the extension of the break-up of plastic A is still good. Plastic D showed an increase in breaking length from a dose of 10-20 kGy, while at a dose of 25 kGy it decreased compared to that stored for one week. This may be caused by crosslinking at a dose of 25 kGy weakening and also due to a parallax error in measuring the breakout extension.

The limitation in this study was that it was unable to observe and explain how many types and types of free radicals were formed on HDPE packaging plastics, both those which were not stored and those stored after gamma irradiation. In theory, irradiated HDPE plastic after being stored for some time will experience mechanical properties. In this study, after it was stored there was a decrease in mechanical properties in the breakdown extension parameters, but the yield strength and tensile strength parameters showed an increase. In addition, this study also cannot show that any increase in radiation dose will result in an increase in the number of free radicals.

This might be explained if free radical testing is carried out. In addition, the observation of the effects of gamma radiation on HDPE plastic in this study is limited to the increase or decrease in mechanical properties, while observing the possible formation of chemical reactions between plastic and gamma rays, which will affect changes in the chemical elements of plastic or the security of usage has not been done. This is due to the limitations of theory and ability and there is no relevant research on this matter. Observation of what the maximum dose is suitable for the purpose of radiation has also not been done well.

However, I think the application of gamma irradiation techniques to HDPE plastic in this study does not affect the safety factor of packaging plastic consumption, assuming that plastic is widely used because it has an inert nature or is not easy to react with the packaged material. In addition, the irradiation process using gamma radiation is a "cold" process because it does not cause a rise in temperature in the material it passes. As a result, changes in chemical elements that occur due to radiation quantitatively are also less. In addition, the maximum radiation dose used in this study only reached 30 kGy, whereas in previous studies larger radiation doses were used.

#### 4. Conclusion

From the research that has been done, it was found that gamma irradiation caused an increase in the mechanical properties of HDPE packaging plastic. The parameters of the mechanical properties tested in this study included yield strength (Ys), tensile strength (Ts), and elongation (Eb). The three parameters have increased compared to before being irradiated, an increase occurs every time a radiation dose is added.

Increased mechanical properties are caused by the formation of free radicals in plastic when gamma irradiation. The free radical species formed cause the formation of cross bonds between plastic molecules, so that the yield strength, tensile strength, and elongation of the break will increase and the force required by the plastic to stretch and break will be greater. The greater the radiation dose given, the more crosslinking of the plastic molecules produced, the more difficult the plastic to stretch and the mechanical properties to increase.

Irradiated HDPE packaging plastic stored for a period of time can experience changes in mechanical properties. These changes can be in the form of increase or decrease in yield strength, tensile strength, and elongation at break. If there is a decrease in mechanical properties it is caused by crosslinking to a weakened plastic molecule. In this study, the reduction in mechanical properties of irradiated HDPE plastic after storage is relatively small, so it is still strong and can be used long enough.

The application of gamma irradiation must be carried out at the right dosage, so that it matches the purpose of irradiation. Gamma irradiation at the appropriate dosage will not affect the safety of use, because gamma irradiation does not cause a temperature increase in the material it passes. As a result, changes in chemical elements that occur due to radiation quantitatively are also less.

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