Examination of the Disposal Procedure for Nuclear Medical Test with ^{125}I through In-vitro Test

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Abstract - Nuclear medicine in vitro tests are performed on an average of 14 million cases annually in Korea. ^{125}I, a nuclear species mainly used for in vitro tests, was estimated to have a longer shelf-life than other nuclides because the half-life was longer than other nuclides. Most institutions have judged that the radioactive waste will be about 1/1000 of the original radioactivity when it was stored for a period corresponding to 10 times the half-life of the radioactive waste, and thus the disposal will be satisfied. However, as the amount of radioactive materials remaining in the waste generated by the mechanization and modernization of the inspection method was reduced, it is necessary to reasonably infer the storage period. As a result, the storage period can be calculated reasonably. Waste generated from this test include tubes, beads, vials, tips, and other miscellaneous flammable substances (tissue paper, gauze, paper, etc.). To estimate the reasonable storage of these wastes, the amount of residual radioactive material was measured using a DREAM GAMMA-10 counter, and the period was calculated based on this value. For the purpose of this study, all tubes and beads used for the tests during the year 2016 were measured at a medical checkup hospital in Seoul. A total of 398,879 testing tubes, with 4,155 tubes per box, with a minimum number of 2,792 and a maximum number of 4,374, were used. As a results indicate, the self-disposable period of the tube was measured as 14 days, the beads as 234 days, plastic vials as 177 days, and gauze as 365 days. It was deduced that there is no economical gain because it is not necessary to store for 1 year and 6 months, 10 times the half-life period of ^{125}I, which was a conservative calculation method.

Key words : In-vitro test, Self disposal, Storage period of waste, ^{125}I

INTRODUCTION

In the field of nuclear medicine testing, the test for analyzing the blood and body fluid removed from the body, is called an in-vitro test. A radioimmunoassay is a method for detecting and quantifying a target substance in a sample using an antigen or an antibody labeled with a radioactive isotope in Table 1. It is possible to detect a very small amount of antigen at a 1 pg level, which can be easily obtained by reacting with blood (Dean 2005). An average of 14 million inspections were conducted annually from 13,706,183 in 2005 to 14,018,172 in 2013. The nuclide used for in vitro testing is ^{125}I, which is the most widely used radionuclide in Korea (KRIA 2013).

In accordance with Article 71 of the Nuclear Safety Law, a nuclear enterprise may dispose of radioactive waste that has been confirmed in advance by the committee in the event that its radioactive concentration is less than a certain value, by means of incineration, landfill, or recycling. ^{125}I has a half-life of 60 days, and its own disposal allowable

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Table 1. Applied organs and details applied by inspection

The name of reagent	Full name	Applied organs	Detailed description
AFP	Alpha-Fetoprotein	Liver	A tumor marker to help detect and diagnose cancers of the liver, testicles, and ovaries.
CA125	Cancer Antigen 125	Ovarian	To monitor treatment for ovarian cancer
CA15-3	Carcinoma Antigen 15-3	Breast	To monitor the response to treatment of invasive breast cancer
CA19-9	Carbohydrate Antigen 19-9	Pancreas	Primarily to monitor response to pancreatic cancer treatment and to watch for recurrence; sometimes to aid in the diagnosis of pancreatic cancer
CEA	Carcinoembryonic Antigen	Large Intestine	To help diagnose celiac disease and to evaluate the effectiveness of a gluten-free diet
cyfra	CYFRA 21-1 Cancer Antigen	Lung	Tumour markers in the diagnosis of lung carcinoma
FER-IZO FER-sin jin	Ferritin	Leukemia, anemia	Find the cause of anemia, especially iron deficiency anemia.
FSH	Follicle-stimulating Hormone	Female hormone	To evaluate fertility issues, function of reproductive organs (ovaries or testicles), or pituitary function In children, to evaluate early or delayed sexual maturation (puberty)
FT4	Free thyroxine (free T4)	Thyroid	To help evaluate thyroid gland function; to help diagnose thyroid disease; to screen for hypothyroidism in newborns; to monitor effectiveness of treatment
LH	Luteinizing Hormone	Female hormone	To evaluate fertility issues, function of reproductive organs (ovaries or testicles), or to detect the release of an egg from the ovary (ovulation); to evaluate pituitary function
NSE	Neuron-Specific Enolase	Lung	An auxiliary test in the diagnosis of small cell lung carcinoma
PSA	Prostate Specific Antigen	Prostate	To screen men for prostate cancer, to help determine the necessity for a biopsy of the prostate, to monitor the effectiveness of treatment for prostate cancer, and/or to detect recurrence of prostate cancer
T3	Triiodothyronine	Thyroid	To help evaluate thyroid gland function; to diagnose thyroid disease, including hyperthyroidism, and determine the cause; to monitor effectiveness of treatment of a thyroid disorder
T4	Thyroxine	Thyroid	To help evaluate thyroid gland function; to help diagnose thyroid disease; to screen for hypothyroidism in newborns; to monitor effectiveness of treatment
Testosterone	Testosterone	Male hormone	To detect an abnormal testosterone level in males and females
TSH	Thyroid-stimulating Hormone	Thyroid	To screen for and help diagnose thyroid disorders; to monitor treatment of hypothyroidism and hyperthyroidism

concentration is 100 $Bq \cdot g^{-1}$ (NSSC 2017a, b). Therefore, it is important to estimate the storage period of waste generated for self-disposal because ^{125}I has a long half-life of nuclides used for nuclear medicine tests (Kim 2014a).

Tubes, beads, vials, tips, and other miscellaneous flammable substances (tissue paper, gauze, paper, etc.) are generated for inspection. Such waste was previously calculated by applying the amount of radioactivity used in the initial test, and the allowable concentrations of disposal for the various substances were calculated. Most of the radioactive waste was disposed of through conservative estimates. Therefore, most of the radioactive waste was stored for over a year and a half before disposal was possible (Lee *et al*. 2017).

However, this was caused by not quantitatively measuring the amount of radioactive material remaining in the actual waste. In addition, the disposal was carried out after estimating and storing the half-life period of the corresponding nuclide ten times.

This study aims to reasonably determine the shelf life of radioactive waste.

MATERIALS AND METHODS

Based on the data of nuclear medicine surveillance conducted in 2016 at a medical examination center in Seoul, the Self-Disposal period was estimated. As can be seen in Fig. 1, a total of 17 items including AFP were applied. The most

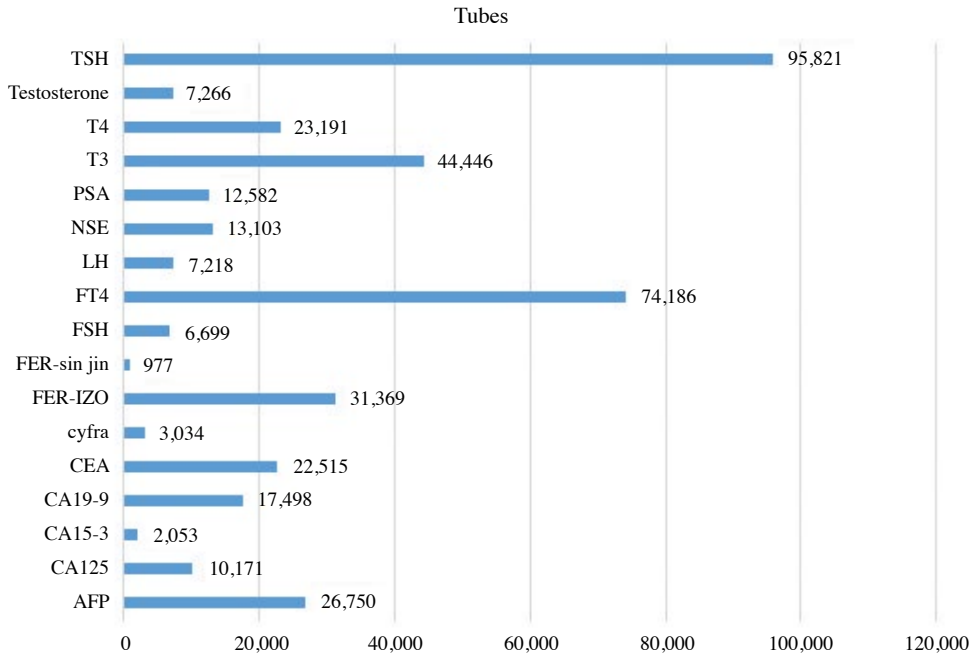

Fig. 1. Number of Nuclear medicine tests conducted in 2016 at the KMT Health Checkup Center.

frequent test among the 398,879 tubes was TSH (95,821), and the lowest test was 977 tubes with FER-sin. A total of 398,879 tubes were stored in a total of 96 boxes for each day of storage, and the period was calculated and discarded. There are 4,155 tubes per box. The days stored in 96 boxes were from 62.4 to 421 days.

The average residual radioactivity of the packed boxes was 2,995 Bq to 280,420 Bq. As can be seen in Table 2, Monthly examinations showed 14% in May and June and 10% in October and November. The radioactivity of the individual tubes was measured using a wall-type DREAM GAMMA-10 Counter in Fig. 2. The detection efficiency for this instrument was 80% for ^{125}I and 0.65 Bq for MDA. The surface radiation dose rate of self-disposed wastes was measured at a distance of 10 cm from the surface of the radioactive waste in the area where natural radiation levels can be confirmed.

"Self-Disposal" means that after disposing of wastes whose concentrations of nuclides have been determined to be less than the specified allowable levels in the radioactive waste owned by the employer, they are regarded as general industrial wastes, not radioactive wastes, Landfill or recycling (Kim 2014b; NSSC 2017a, b). The wastes to be disposed of separately were separated and stored, and other wastes were not mixed. When the stored wastes meet their self disposal time, a "Nuclear Waste Disposal Plan" was submitted to the Korea Institute of Nuclear Safety (NSSC 2017a).

Table 2. Percentage of monthly nuclear tests - This test is performed like a health checkup, so it is mainly performed before the holiday period and before the end of the year

Month	Tubes	Monthly rate
1	12,360	3%
2	10,245	3%
3	24,489	6%
4	34,153	9%
5	57,370	14%
6	54,120	14%
7	43,661	11%
8	34,046	9%
9	25,846	6%
10	39,750	10%
11	40,254	10%
12	22,585	6%
Total	398,879	

After receiving a notice of conformity, the waste is disposed of itself. The surface radiation dose rate was measured to confirm that there was no difference from the level of natural radiation at its disposal. Dosimetry values are not affected by other nearby sources or waste. The waste to be disposed of has been entrusted to the "medical waste" disposal agent according to the "Waste Management Act". This waste is incinerated by the intermediate supplier, and the incinerator is disposed of by the finalist.

Table 3. ^{125}I name of the test, annual usage, individual radioactivity, average weight of the tube and vial - For hepatitis screening, additional beads are required in addition to the test tubes

No.	Inspection name	Usage in 2016 (kit)	Usage proportion (%)	Individual radioactivity (kBq·kit^{-1})	Volume (ml·kit^{-1})	Weight of tube (g)	Weight of vial (g)
1	Testosterone	74	1.9	77.7	50	2.75	67.35
2	T3	448	11.2	185	24	2.53	10.6
3	T4	228	5.7	185	24	2.53	10.6
4	FreeT4	755	18.9	185	35	2.53	12.3
5	NSE	137	3.4	296	24	2.53	10.6
6	FSH	68	1.7	592	12	2.75	10.6
7	CEA	217	5.4	592	12	2.53	12.3
8	PSA	122	3.1	592	12	2.53	12.3
9	CA125	100	2.5	592	8	2.53	12.3
10	FERRITIN	328	8.2	740	21	2.75	7.2
11	LH	73	1.8	799	8	2.75	10.6
12	TSH	970	24.3	799	8	2.53	10.6
13	CA19-9	166	4.2	799	8	2.53	12.3
14	CA15-3	18	0.5	799	8	2.53	12.3
15	cyfra	31	0.8	980	11	2.75	7.2
16	AFP	255	6.4	814	24	2.53	12.3
Annual usage		3,998	100				
Average weight						2.6	11.1
1	Hepatitis (eAgAb)	8	0.2	592	8	Bead 0.14 g	12.3

Fig. 2. DREAM GAMMA-10 - This machine is a device that measures gamma activities and has a well type detector built in, which is excellent in detection efficiency.

Table 4. Individual weight and flammability of waste generated - used in 2016

Waste type	Flammability	Average weight	Cap. of container
Tube	Flammability	2.6 g	63 L
Bead	Non-combustible	0.14 g	12 L
Glass Vial	Non-combustible	67.35 g	13 L
Plastic Vial	Flammability	11.0 g	29 L
Plastic Tip		0.28 g	
Dispenser	Flammability	5.37 g	34 L
Gauze		1.36 g	

RESULTS AND DISCUSSION

In the ^{125}I RIA test, 15 species of T3 and one species of hepatitis were tested in Fig. 1. As can be also seen the percentage of monthly nuclear tests in Table 2. This test is performed like a health checkup, so it is mainly performed before the holiday period and before the end of the year. The most frequent TSH test was 24.3% of all tests. The average weight of the test tube was 2.6 g in Table 3. The containers used in the testosterone test were glass, weighing 67.35 g in Table 3. All containers used in the tests were made of plastic. The radioactivity per kit is shown in the table below.

The total volume of radioactive waste classified by type was 63 liters of test tubes, 12 liters of beads, 13 liters of glass vial, and 29 liters of flammable plastic vial in Table 4. Other plastic tips, dispensers and gauze totaled 34 liters. It shows the calculation results of the storage period of other flammable waste in Table 5. It is listed the mean, standard deviation, and relative standard deviation in Table 6. Concentrations of radioactive materials used for each test were shown in Table 7. T3 test was the highest amount of radio-

Table 5. Date of storage of other flammable waste

Namez (weight)	Specific activity	Storage cycle (n)	Date of storage
Plastic tip (0.28 g)	$\frac{998}{0.28}=3{,}564\ \mathrm{Bq}\cdot\mathrm{g}^{-1}$	$n=\frac{\ln\left(\frac{100}{3{,}564}\right)}{\ln(1/2)}=5.16$	$5.2\times60=312$
Dispenser (5.37 g)	$\frac{9{,}988}{5.37}=1{,}860\ \mathrm{Bq}\cdot\mathrm{g}^{-1}$	$n=\frac{\ln\left(\frac{100}{1{,}860}\right)}{\ln(1/2)}=4.22$	$4.2\times60=252$
Gauze (1.36 g)	$\frac{9{,}980}{1.36}=7{,}338\ \mathrm{Bq}\cdot\mathrm{g}^{-1}$	$n=\frac{\ln\left(\frac{100}{7{,}338}\right)}{\ln(1/2)}=6.0$	$6.0\times60=360$

active material remaining in the tube after testing and lowest in the AFP test.

1. Flammable tube

The measured value per minute of the waste box containing the tube was 16,708 cpm. From this value, it was possible to calculate the storage period satisfying 100 $\mathrm{Bq}\cdot\mathrm{g}^{-1}$ by dividing measurement efficiency and one tube. The shelf life was calculated in multiples of half-life. As can be seen. In the case of a flammable tube, it was calculated to be about 25 days which is 0.42 times the half life in Equation 1.

$$100(\mathrm{Bq/g})=\frac{16{,}708\ \mathrm{cpm}}{60\ \mathrm{sec}\times0.8\times2.6\ \mathrm{g}}\times\left(\frac{1}{2}\right)^{n}$$
$$\therefore\ n=\frac{\ln\left(\frac{100}{133.8}\right)}{\ln(1/2)}=0.42 \quad (1)$$

2. Non-flammable bead

The non-flammable beads made up 7,094 cpm, and the storage period was calculated in the same way, and with an n value of 3.399, which takes about 204 days in Equation 2.

$$100(\mathrm{Bq/g})=\frac{7{,}094\ \mathrm{cpm}}{60\ \mathrm{sec}\times0.8\times0.14\ \mathrm{g}}\times\left(\frac{1}{2}\right)^{n}$$
$$\therefore\ n=\frac{\ln\left(\frac{100}{1{,}055}\right)}{\ln(1/2)}=3.399 \quad (2)$$

3. Non-flammable glass Vial

Non-flammable glass vials are mainly used for testosterone testing. The radioactivity of testosterone was 1.554 $\mathrm{kBq}\cdot\mathrm{ml}^{-1}$ at 50 ml and 77.5 kBq, and 155 Bq/0.1 ml at 0.1 ml. Therefore, if the storage period satisfying 100 $\mathrm{Bq}\cdot\mathrm{g}^{-1}$ is calculated, It can be seen that the weight of the glass vial is a waste that can be disposed of immediately upon occurrence.

Table 6. Mean, standard deviation, and %CV values by inspection

Name	Mean (CPM)	S.Dev of CPMs	%cv
AFP	272	15.1	0.085
CA125	397	19.6	0.130
CA15-3	2,060	44.8	0.090
CA19-9	2,433	48.8	0.036
CEA	659	25.2	0.056
cyfra	3,489	57.6	0.110
FER-IZO	14,726	120.4	0.029
FER-sin jin	8,060	89.5	0.038
FSH	5,102	69.6	0.048
FT4	23,466	151.6	0.014
LH	1,778	41.4	0.080
NSE	2,384	46.7	0.208
PSA	1,757	41.3	0.060
T3	23,052	150.8	0.020
T4	7,204	82.2	0.068
Testosterone	1,250	35.2	0.114
TSH	5,226	71.6	0.017

4. Flammable plastic Vial

The plastic vials were subjected to a TSH test with a high radioactivity used for the examination. The amount of radioactivity used for TSH testing is 799 kBq/8 ml in Table 3.

The radioactivity value was estimated to be 9,988 Bq/0.1 ml when the remaining amount on the inner surface of the vial was estimated to be 0.1 ml. The storage period "n" was calculated to be 3.24, which means that it is possible to dispose of after storage for more than 194 days.

5. Other flammable substances

Miscellaneous flammable substances include plastic tips, dispensers, and gauze, which are generated in the course of

Table 7. The concentration of radioactive material and the average measurement value

Name	Initial input concentration ($Bq \cdot tube^{-1}$)	Average CPM per tube	Average residual concentration ($DPS \cdot tube^{-1}$)	Tube remaining ratio
AFP	8,140	272	5.67	0.07%
CA125	5,920	397	8.27	0.14%
CA15-3	7,990	2,060	42.92	0.54%
CA19-9	7,990	2,433	50.69	0.63%
CEA	5,920	659	13.73	0.23%
cyfra	9,800	3,489	72.69	0.74%
FER-IZO	7,400	14,726	306.79	4.15%
FER-sin jin	7,400	8,060	167.92	2.27%
FSH	1,850	5,102	106.29	5.75%
FT4	5,920	23,466	488.88	8.26%
LH	7,990	1,778	37.04	0.46%
NSE	2,960	2,384	49.67	1.68%
PSA	5,920	1,757	36.60	0.62%
T3	1,850	23,052	480.25	25.96%
T4	1,850	7,204	150.08	8.11%
Testosterone	777	1,250	26.04	3.35%
TSH	7,990	5,226	108.88	1.36%
Average residual rate				3.78

the experiment. When the gauze was wiped for decontamination of the contaminated part, the non-radioactivity was the highest, and thus the storage period was calculated as gauze.

The TSH test, which has the highest frequency of use and the highest radioactivity, was applied to the test kit. For the TSH test, the radioactivity of the test kit was 799 kBq/8 ml in Table 3. The weight of a plastic tip is 0.28 g, and assuming that 10 μl is left in the tip, it becomes 998 Bq. If the dispenser weighs 5.37 g, and it is assumed that 100 μl remains, the radioactivity is 9,988 Bq. The gauze weighed 1.36 g and assuming that 100 μl of gauze remained, a calculation period of 9,988 Bq is yielded.

CONCLUSION

For all waste, storage periods shorter than the original self-disposal period of one year and six months were calculated. The test tube was disposable after 14 days of storage, and the bead was stored for about 8 months after 234 days.

Plastic vials should be stored for 177 days for about 6 months, and other flammable wastes were stored for about 1 year after 365 days.

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REFERENCES

Dean L. 2005. Blood Groups and Red Cell Antigens, pp. 97-98. In: Blood transfusions and the immune system, National Center for Biotechnology Information (NCBI), National Library of Medicine, National Institutes of Health, Bethesda, MD 20892-6510.

Kim CB. 2014a. Measurement and Estimation for the Clearance of Radioactive Waste Contaminated with Radioisotopes for Medical Application. Dongshin University. Department of Radiological Physics, School of Public Health, School of Public Health, pp. 14.

Kim CB. 2014b. Measurement and Estimation for the Clearance of Radioactive Waste Contaminated with Radioisotopes for Medical Application. Dongshin University. Department of Radiological Physics, School of Public Health, School of Public Health, pp. 15-18.

Korea Radioisotope Association. 2013. Statistics on the Radiation Practices in Korea, 39p.

Lee KJ, Sul JH, Lee IW and Park YJ. 2017. Discussion about the Self Disposal Guideline of Medical Radioactive Waste. *J. Nuc. Med. Technol.* **21**(2):13-27.

Nuclear Safety and Security Commission. 2017a. Enforcement Decree of the Nuclear Safety Act. Article 107.

Nuclear Safety and Security Commission. 2017b. Regulation on the classification of radioactive waste and its self disposal standards. Article 2.

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