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Research paper

Smart management and control system for liquid radioactive waste in hospitals using neural network techniques

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Abstract

In tertiary hospitals where the nuclear medicine services have been introduced, the radioactive materials used in diagnosis and / or treatment need to be handled. The hospital design and medical planning should consider such these materials and their policy for treatment. The nuclear wastes have been divided into solid and liquid based on the used materials and for their half-life times which start from few minutes till reaching years. In our study, the most common radioactive liquid materials (wastes) have been treated by smart system. The system will detect the material of the waste via nuclear sensors and based on its HLT (activities), it will be distributed in two shielded storage tanks classified based on capacity then to the sewage treatment plant (STP) of the hospital after keeping for required times. The location and capacity of these tanks together with their monitoring and control system should be considered in design stage which determines the treatment processes. By applying our proposed technique on two hospitals, the results have reduced the storage tank capacity by 87% (reduction) and space area leading to cost reduction by 72% keeping the maximum level of safety.

Keywords: *Delay Tanks; Iodine-131; Isolation Wards; Radioactive Wastes.*

1. Introduction

For advanced process in diagnosis and therapeutic, the radioactive isotopes are used in hospitals which considered as one of the important peaceful uses of atomic energy. Many regulations have been implemented to monitor how the worker receive the radioisotopes, how be used in safe manner inside healthcare facilities, and how can be discarded [1-3]. An important aim in radioactive waste management is to ensure that the radiation exposure to persons (Public, Radiation worker, Patient) and the environment does not exceed the prescribed safe limits.
To determine the maximum limits, the nuclear wastes should be clustered. It has been classified based on the shape / status; radioactive waste can be classified into 1) - vapours which can be discarded via nuclear fume hood and / or safety cabinet, 2)- (Solid / Liquid materials (un-used materials)) materials will be returned back to (nuclear source driven) or stored in a temporary storage trolley (TST) after labelled with patients' numbers, 3)- nuclear drainage via human waste ((toilets); stools, urine). TST is a lockable type trolley designed and fabricated specially to keep and protect these materials. The nuclear drainage should be kept in storage spaces (tanks/ trolleys) for certain times before releasing to sewage treatment plant. A well-designed waste storage trolley is found to aid in decaying the I-131 wastes from wards and nuclear medicine toilets before releasing to waste treatment plant. Another concept is to use two storage tanks with collection time of about two months and delay time of two months. The management of radioactive wastes collected from nuclear medicines has been coordinated internationally and documented [4-7]. This waste must consider permissible concentrations applicable from the standpoint of community safety; ensure that the degree of dilution envisaged is achieved at the discharge point and to signify the hazard to the general population. Based on many international regulations, the radioactive waste should be stored for a minimum period of 10 half-lives when after decay only 0.1% of the initial activity remains but it will depend on material type and activity. Many radioactive materials can be used as Technetium-99m (Tc-99m) with average decay time (6 hours), Iodine-131, -125, -123 (8-60 days decay time), Flourine-18(F-18) (110 minutes), Tritium (H-3) and Carbon-14(C-14). Most procedures have been carried out with (99mTc) Technicium-99m formulations; and a limited number by using m-Iodobenzyl guanidine (MIBG) (131I) and gallium-67 (67Ga). 10 µSv/h or less is the maximum allowable exposure rates at distance 1 meter based on international regulations [8-11] to release with hospital sewage. Wastes of 99mTc can mix with normal wastes after a 48-hours delay. Others for long - lived radioactive isotopes undergo minimum of 2-months decay before these are released. The releasing process should be performed after monitoring by the department's medical physicist using a window for Geiger Muller (GM) survey meter [12-15]. The storage/dark tank capacities should be calculated based on waste quantities discarded from basins and patient toilets together with number of patients admitted each day.
Before estimating the required capacity of dark tanks, it should determine the radioactive material sources as Gamma, PET-CT, and Brachy therapy which are most common modalities in hospitals. A survey has been applied for 10 tertiary hospitals to determine the number of equipment needed. As illustrated in table 1, the hospitals and their equipment.

Table 1: Most Common Modalities Related to Radioactive in 10 Distributed Hospital

#	Gamma-1	Gamma-2	PET	PET-CT	Brachy	Notes
H-1	x	x		x	x	Having radio-therapy
H-2	x		x			
H-3				x		
H-4	x		x			Having radio-therapy
H-5	x	x		x	x	Having radio-therapy
H-6	x	x		x	x	Having radio-therapy
H-7				x		
H-8				x		
H-9	x	x		x	x	Having radio-therapy
H-10	x	x		x	x	Having radio-therapy

As indicated in previous table, 50% of the studied hospitals have two gamma equipment, PET-CT and bunker for brachy-therapy. The most common areas of nuclear wastes are considered in table-2 considering that hand wash basins at patient toilet may be connected to normal drain system and / or connected to nuclear line with water tap controlled by systems as IR sensors that to control the amount of water and to reduce the possibility of filling the reservoir.

Table 2: Areas of Nuclear Wastes in Hospital

Room Name	Basin/ Toilet
Immuno Lab	Basin
PET-CT Hot Lab	Basin
Gamma Hot Lab	Basin
Brachy therapy Hot Lab	Basin
Isolated ward Toilet	Toilet
Isolated ward Toilet	Toilet
Toilet	Toilet
Toilet	Toilet

By considering the average number of patients admitted into hospitals though three months after full occupancy (one year after start of operation). The estimated capacity of tank is indicated in table 3.

Table 3: Average Number of Patients Deals with Modalities

Patient/ modality	Gamma-1	Gamma-2	PET-CT	Brachytherapy	Total
# patients /D	10	10	10	2	
# patients /Month (22 working Days)	220	220	220	44	
80% for Gamma 100% for PET & Brachytherapy have Toilet	176	176	220	44	
10L /patient	1760	1760	2200	440	6160

The tank capacity is ~9 m^3 (1.5 times the required volume as safety margin). The tank should be leak proof, corrosion free so it may be constructed from Stainless Steel, Concrete or High Density Poly-Ethylene (HDPE). The tank should be shielded or to be under ground in safe area to prevent radiation from surround zone.

A facility admitting many patients per day would require two or more delay tanks of (9000 liters each) as indicated in the following figure 3. This capacity is based on the presumption that on an average each patient uses about 10 litters (7 liters per flush (LPF), and there are high efficiency toilets that use up to ~6 LPF) of waste per case (once per test as urine and stool including washing). At that rate, patients will use ~6000 liters per month. As such, each tank holds the radioactive waste for ~2 months that is sufficient for the decay of Iodine to low levels (Delay & Decay). However before releasing the effluent of the tank into the public sewerage system a sample is collected to check the activity, this should not be more than 1.2 micro-curies per liter (the allowable margin). In case of emergency (the tanks are full, and valves or pumps have been damaged), some techniques may be used to cover new drainage (new amount of drainage). Although this technique has been applied in many hospitals, it has drawbacks; the first one is to have at least ~ 20 M2 (divided into two adjacent tanks) underground and should be considered in early stage (through medical planning) before building the hospital. The second is to have good shielding materials to isolate wastes and to protect persons. The third is that the number of patients has used iodine is ~2 – 3 % which need long delay time (~ 60 days). The fourth is that waste collected by the end of first month and having iodine will not delayed to 60 days by the end of second month. The three following figures indicate the current solutions used in hospitals to deal with radioactive wastes through delay tanks. The first figure indicates that hospital does not store nuclear wastes and release directly to STP although it is incorrect but not prohibited in some developing countries.

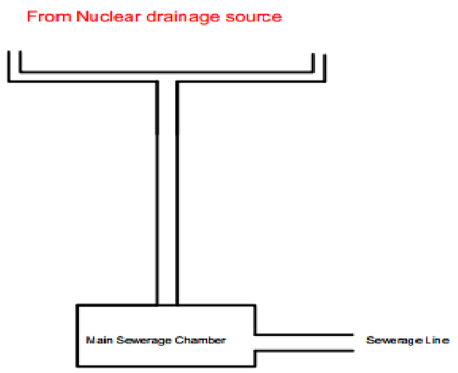

Fig. 1: Direct Connections between Nuclear Waste and STP.

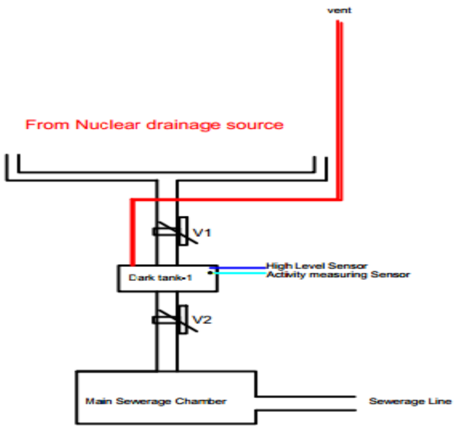

Fig. 2: Nuclear Wastes through Single Storage Tank then STP.

The second solution has been introduced in some hospitals to store waste for certain time explaining that number of patients is not large, and the storage tank can store waste for long time.

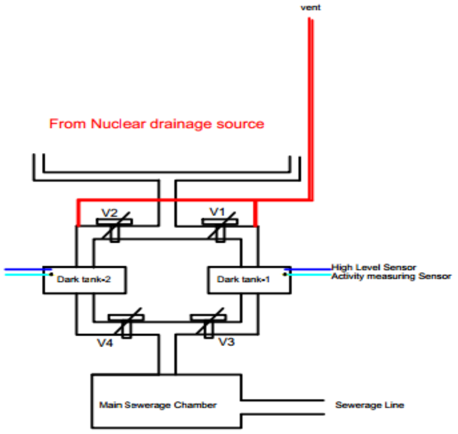

Fig. 3: Nuclear Wastes through Two Equal Alternative Storage Tanks then STP.

The third solution is the most common one which applied in many advanced hospitals (which has been introduced by very well reputed company in medical planning and implementation). This solution is to have two equal storage tanks; every tank can store the estimated / calculated capacity collected from nuclear medicine department within one month at least (two months preferred). The first tank will start its storage by beginning the first month and will be closed by the end to convert the pass way into the second tank to the end of second month. After two months, the collected wastes of first tank can be released to STP.

2. Methodology

Our proposed technique has considered all previous drawbacks of the third solution by using neural network algorithm that have four inputs and two outputs [16-20]. The four inputs are the outcome of four dedicated sensors implemented on the four collected lines from hot labs / nuclear patient toilets.

Based on the material activities, the sensor will send signal to smart system (neural network) which process the signals and compare to certain thresholds and determine the direction of waste to be stored either to traditional nuclear waste tank or to long delay storage tank (Iodine). As illustrated in figure 4, the neural network has been constructed from four inputs, one hidden layer and two outputs. A feed forward network structure containing an entry layer, a hidden layer and output layer was used. After the ANN structure was developed, it was normalized within the 0–1 value set using to improve the training characteristics of the data set. The training data set was used to determine ANN neuron and bias weight values for obtaining the lowest error value.

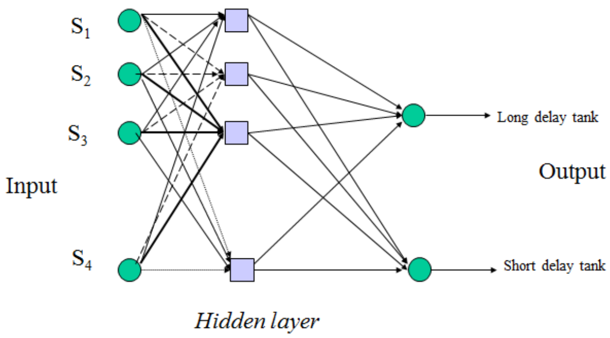

Fig. 4: Proposed Neural Network.

The proposed system has been implemented in figure-5 which has two storage tanks one is 1.5 M3 instead of 9 M3 of previous system and the second is less than 1 M3 (0.2 M3) instead of 9 M3 of previous system. Although the first tank can be discharged / released every two days, the estimated capacity will lead to discharge it every week (two days off after the five working days) to grantee that the latest quantity of waste has been kept at least 48 hours. For the long delay tank, it has multiplied five times to keep long period more than 10 months for more than 3% of patients deal with long radioactive delay materials. Four controlled valves have been used to control the waste after having the decision which tank will be filled. V1 and V2 will control the long and short delay tanks respectively while V3 and V4 will release the waste to treated sewage. Level switches have been provided to monitor the effluent levels.

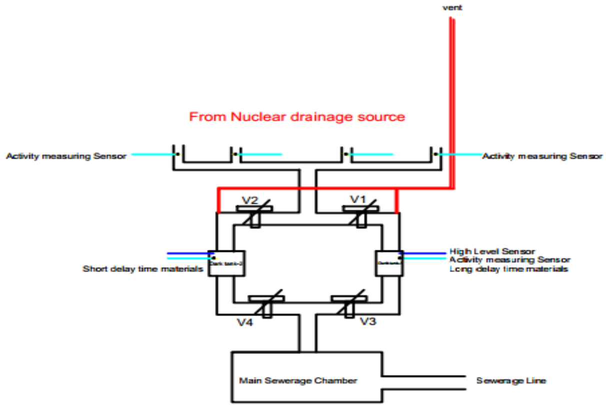

Fig. 5: Nuclear Wastes through Two Dedicated Storage Tanks then STP.

By reaching more than 80% of tank volume via Business management system (BMS) which indicates percentage volume of effluents by hooter alarm, the submersible pumps will deal with waste. Figure-6 illustrates the required process / flowchart which compare the activity of the sensor to certain threshold to pass or not then compare it again to the determined value which classify the material into tank-1 (long delay tank), or tank-2 (short delay tank).

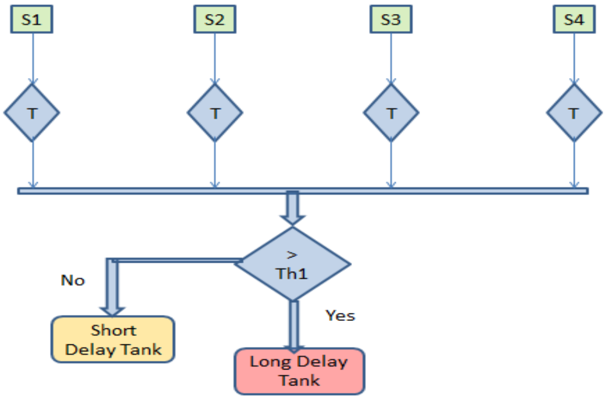

Fig. 6: Flowchart of the Classification Process Based on Neural Network.

3. Results

The radioactive waste should be kept reaching for safe level before releasing to sewage plant. Different techniques have been implemented to cover this problem starting from neglecting this issue and release direct to sewage in some developing countries till reaching for dual storage tanks operated alternatively. The proposed techniques have provided a smart technique based on neural network by determining the activities of short and long delay decay materials. These activities have been weighted after detecting by radioactive sensors then processed and compared to certain threshold based on their quantities and activities. Based on processed data, the smart system will have the decision by opening valve V-1 or Valve V-2 to be stored in long / short delay tanks, respectively. This technique has reduced the required storage area from 18M3 to 2.5 M3 as indicated in table 4.

Table 4: Comparison between Old and Our Proposed Technique

Item	Old technique	Proposed technique
# tanks	2	2
Storage volume M^3	18	2.5
Storage area M^2 (20 cm) thickness	80	15
concrete and shielding material cost 1750 $ /m	140000	26250 + 14000 (sensors and system)

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