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Original Article

BioChroma – A New and Patented Technology for Processing Radioactive Wastewater from Nuclear Medicine Therapy Facilities in Hospitals and Clinics

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Abstract

After undergoing radionuclide therapy, patients generate wastewater with a considerable amount of radioactivity, which can reach levels of as much as 90% of the administered dose. Due to the risk of accumulation after discharge into the sewer, it is advisable to collect this effluent for its treatment prior to final discharge. Delay and decay (natural decomposition of the isotope) is the most commonly used technical method of abating radioactive iodine, but it is frequently criticized as being complex and very expensive. BioChroma is a technology that has been developed as an alternative to these complicated and expensive systems. This paper describes this new technology and presents, as an example, a system that was installed and successfully commissioned in the middle of 2008 in a nuclear medicine ward with 12 beds in Stuttgart (Germany). Based on existing legislation, the responsible authorities and the company that operated the hospital agreed on a maximum activity level of 5 Bq/l. If a typical delay and decay system would have been installed, the 180 m^3 treatment plant that was already available in the hospital cellar would have to be extended by additional 150 m^3. By implementing the patented BioChroma process, the space requirements were reduced by 75%. For instance, since the new system was integrated into the existing installation, tanks accounting for 120 m^3 could be used as buffering volume in the new wastewater treatment plant. The operation of the referred plant is currently producing very good results with values below the specified limit of 5 Bq/l for the isotope ^{131}I. In addition, ^{90}Y has been reported to be eliminated at the same time. Over the past 2 years of operation, the wastewater treatment plant has been able to achieve a maximum processing capacity of more than 2,000 l/day, which equates to a nuclear medicine ward with approx. 20 beds. The highest level recorded during the test period (of 180 days after start-up) was a peak of nearly 2,800 l/day.

Keywords: Radionuclide therapy, I-131, sewer, discharge, effluent treatment, delay and decay

Introduction

While undergoing nuclear medicine therapy using ^{131}I radioisotope at a hospital, patients generate wastewater with a considerable amount of radioactivity. Thus, contamination can reach levels of as much as 90% of the radioactive dose administered to the patient, depending on the type of therapy the patient underwent.[1,2] Given its radioactive half-life of 8.02070 days, there is a significant risk of ^{131}I radioisotope accumulation after its discharge into the sewer network (through sanitary wastewater) and into the environment. Therefore, it is advisable to collect this effluent in a separate system for its treatment prior to final discharge to the municipal sewer.[3-8]

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In spite of the clear scientific evidence of the severe contamination of this specific type of wastewater, a harmonized legal framework has still not been devised for all member states of the European Union.[9] A survey conducted by the Radiological Protection Institute of Ireland clearly spotlights the discrepancies existing among concepts for managing radioactively contaminated effluents. The survey examined 13 countries, 6 of which

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stipulate the installation of wastewater treatment systems [Table 1], 3 of which permit the wastewater to be discharged directly following dilution [Table 2], and 4 of which permit both options [Table 3], depending on the specific conditions of the respective sanitary system.[10]

Delay and decay (natural decomposition of the isotope) is the most commonly used technical method of abating^{131} I, but it is frequently criticized as being complex and very expensive.[10-14] While searching for alternatives to this proven but somewhat old-fashioned technology, an alternative method called BioChroma was developed. This paper describes the technology and presents, as an example, a system that was installed and commissioned in the middle of 2008 in a nuclear medicine therapy facility with 12 beds in Stuttgart (Germany).

Description of the BioChroma process

BioChroma is a new and patented biological treatment system with a final adsorption phase. This technology is based on a thorough optimization of wastewater treatment concepts, which are based on the physical principle of chromatography and were developed and built in the late 1970s for hospitals in Wuppertal and Würzburg (Germany). The performance of these systems at the biological treatment stage was inadequate. As a result, the adsorption stage using activated carbon did not perform as well as it had been expected. All of which resulted in very expensive operating costs since the activated carbon had to be replaced frequently and increased manpower resources were needed to operate the system.

Delay and decay technology [Figure 1] was developed as a result of this failed attempt and it became the standard approach to handle this kind of wastewater. This type of treatment plant is subject in Germany to the stringent provisions of the "Radiation Protection Ordinance" (Strahlenschutzverordnung),[15] which also governs the operation of radiological treatment wards. The Ordinance is joined by the DIN 6844-1[16] and DIN 6844-2[17] standards, which define the binding appliances and equipment that must be used by nuclear medicine diagnostic and therapy facilities, including the systems for processing radioactive wastewater. Taken altogether, these standards and regulations make the design and construction of delay and decay systems very complex. BioChroma was developed as an alternative to these complicated and expensive systems, whereby the fundamental elements of the chromatography-based technology were used and optimized in a way that mistakes of the past could be avoided.

The BioChroma system [Figure 2] collects the wastewater generated at the radiological therapy ward in buffer tanks fed by special pumps, which are fitted with a device that shredders the solid matter and thus homogenizes the

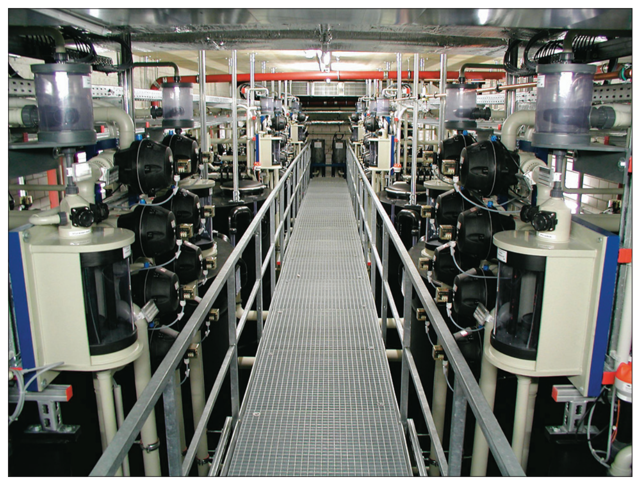

Figure 1: Example of a delay and decay system installed at the Robert Bosch Hospital (Stuttgart, Germany) [EnviroDTS]

Table 1: List of countries that stipulate the installation of a wastewater treatment plant for patient excreta[10]

Country	Management approach		Notes
	Direct discharge	Wastewater treatment	
France		✓	Effluents eliminated by patients in protected rooms (iodine dose > 740 MBq) are normally collected via bisectional toilets. Effluents from ordinary sanitary installations in the nuclear medicine unit are usually linked to a septic tank. Due to the length of time the material stays in the septic tank. The volume activity of the radionuclides in the collector is thus greatly reduced before release into sewage network
Germany		✓	All facilities are required to have holding tanks installed and discharges from facilities must remain below a limit of 5 Bq/l at the point of discharge into the public wastewater network
Northern Ireland		✓	Decay storage is used, although it is not a regulatory requirement. Activity concentration limit is set at 80 kBq/l prior to discharge to sewer
Lithuania		✓	Wastewater is retained in holding tanks for between 30 and 60 days prior to discharge to sewer. Two tanks are used, one being filled as the other is left to decay prior to discharge
Luxemburg		✓	All new treatment facilities are required to install holding tanks, with patient excreta being held for a minimum of 210 days prior to discharge. Activity concentrations of ^{131}I in discharges from the holding tanks to sewer should remain below 5 Bq/l
The Netherlands		✓	Radioactive waste with radionuclides with half-lives below 100 days should be stored for up to 2 years to allow for decay. No specific mention is made or requirements for patient excreta

effluent. Equipped with an aeration system, these holding tanks act as a precursor to the biological treatment stage, as well as they help to avoid anaerobic processes and their associated problems of unpleasant odors.

Table 2: List of countries that allow direct discharge of patient excreta after dilution[10]

Country	Management approach		Notes
	Direct discharge	Wastewater treatment	
Denmark	✓		In Denmark there is no limit for the total activity that can be discharged (that is controlled by limits for purchase and use.) However, dilution of ^{131}I discharges to 0.1 MBq/l required at the point where the hospital drain meets the municipal sewer
Finland	✓		Discharge limits from institutions do not apply to patient excrete that may be freely discharged to sewer as long as discharges at any one time do not exceed 100 MBq and that over the course of a year does not exceed 100 GBq
Sweden	✓		Free release to sewer is the preferred option. Decision based on direct measurements at a large hospital. External radiation exposure to sewer worker of ~2 µSv calculated on basis of 50 GBq ^{131}I per year direct release to sewer

Table 3: List of countries that permit both approaches to patient excreta management[10]

Country	Management approach		Notes
	Direct discharge	Wastewater treatment	
Greece	✓	✓	Direct discharge to sewer allowed, provided that the wastewater is readily dispersible in water and the maximum concentration of radioactive substances is not greater than 3.7 MBq/l. For ^{131}I thyroid post-operatory therapy wastewater decay storage prior to discharge to sewer is required to meet this criterion
Republic of Ireland	✓	✓	Both direct discharge to sewer and use of holding tanks are currently employed. Hospitals are granted with authorisation on activity being administered
Spain	✓	✓	Clearance levels are used to determine disposal routers. Where activities are above clearance levels waste should be stored for decay
Great Britain	✓	✓	Direct discharge to sewer allowed, but sites are required to demonstrate BPM and that the critical group dose constraint of 300 µSv/y is not exceeded. Consideration being given to use of delay thanks for new facilities undertaking treatment of large numbers of patients with ^{131}I

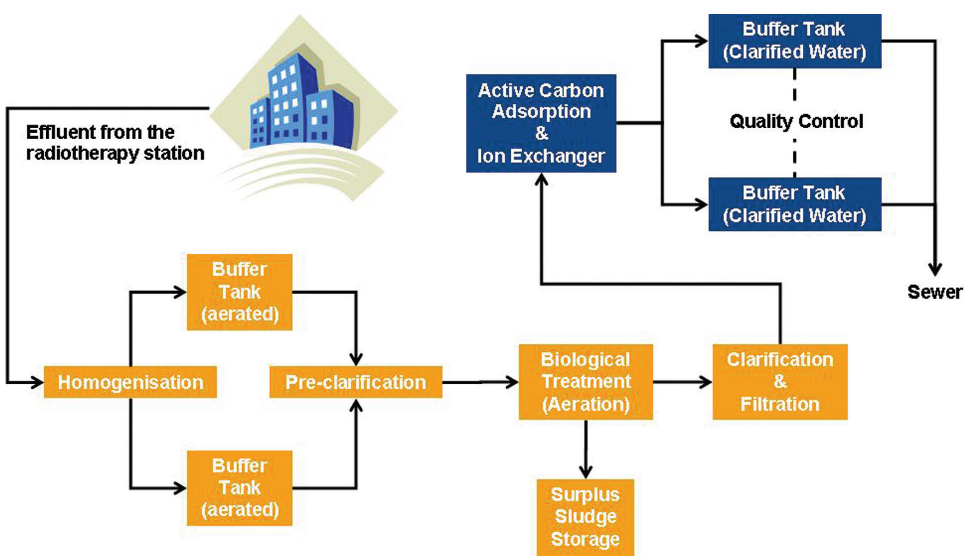

Figure 2: Flowchart describing the BioChroma process

Before reaching the biological treatment plant, the wastewater is preclarified at a sedimentation stage, where larger particles, which might hinder the performance of the activated sludge in the biological reactor, are separated.

The next process step is an optimized biological treatment plant that is installed upstream of the final adsorption and filtration stage. This biological reactor is comparable to a small plant for processing municipal wastewater. It is equipped with a secondary clarification stage and a filter to separate any suspended solids. Thus, final organic contamination is reduced to a minimum and the downstream adsorption filter system can be protected against undesired clogs.

The already mentioned final adsorption filter line consists of activated carbon filters and selective ion exchangers for eliminating the dissolved radioactive components in the wastewater before it is collected in the final storage tanks, where it is subject to constant monitoring, before being ultimately discharged into the sewage system.

Advantages of the BioChroma system

The advantages offered by the BioChroma technology compared with processing systems based on the delay and decay principle are summarized in the following list:

- The technology is patent protected.
- Overall space requirements can be reduced by 50% thanks to its high degree of technological innovation and lower requirement of reaction volumes.
- The combination of the various process steps allows a more flexible continuous operation.
  - The system provides sufficient capacity to absorb sudden peaks, thus offering considerably enhanced comfort to final users (e.g., unlimited shower water operation).
  - The nuclear medicine department can be temporally extended (by up to 30 %) on short notice.
- Unpleasant odors do not present any problems whatsoever throughout the entire system, due to the absence of anaerobic zones.
- A fully automated operation allows savings in personnel costs.
- Elimination of the risk of possible leakages or cross-contamination of the various radioactive effluents (a main issue to be dealt with in delay and decay plants).
- Fewer safety measures have to be taken, since large holding tanks and their associated collecting basins (which are normally installed in systems that adopt the delay and decay principle) are not needed anymore.
- Thanks to their modular design, BioChroma systems are easy to install, irrespective of any on-site obstacles (e.g., cellars with a difficult access).

One additional and extremely significant advantage is the service life of about 5 years that can be achieved by active carbon filters and ion exchangers, which is much higher than that of other technologies. This high availability of the system is confirmed by experience gained with systems such as the one that has been installed at the Helios Clinic in Wuppertal (Germany), where the active carbon filters and ion exchanger resins did not need to be replaced even after more than 5 years of operation.

Hitherto, the following hospitals have been and will be equipped with BioChroma [Table 4]:

Katharinen Hospital (Stuttgart) – Project description

A new nuclear medicine ward with 12 beds was planned for construction in the city of Stuttgart. Based on existing legislation, the responsible authorities and the company that operated the hospital agreed on a maximum activity level of 5 Bq/l of the radionuclide ^{131}I in the final wastewater. If a typical delay and decay system would have been installed, the 180 m^3 treatment plant that was already available in the hospital cellar would have to be extended by additional 150 m^3. By implementing the patented BioChroma process, the space requirements were reduced to a minimum. For instance, since the new system was integrated into the existing installation, tanks accounting for 120 m^3 could be used as buffering volume in the new wastewater treatment plant.

In the case of conventional delay and decay systems, water volume that can be processed each day is directly dependent on the total volume of the tanks and the ratio of initial activity to final activity of the radioisotope. The following formula can be used to calculate the number of patients:

$$n_{pacient} = \frac{\lambda \cdot V_{\tan k} \cdot (n_{\tan k} - 1)}{\Delta V_{paciente} \cdot (\ln A_{initial} - \ln A_{final})}$$

$\Delta V_{\text{patient}}$ = volume of water/patient/day

λ = decay constant = $\ln(2)/t_{1/2}$

V_{tank} = volume per tank

n_{tank} = number of tanks

A = radioactive activity

Figure 3 shows some curves representing the largest

Table 4: Reference list of hopitals that are already or will be soon implementing the BioChroma technology

Name	No. of beds	Country	Year of commissioning
Helios Clinic, Wuppertal	14	Germany	2005
Katharinen Hospital, Stuttgart	12	Germany	2007
University Clinic, Jena	10	Germany	2009
Helios Clinic, Bad Saarow	11	Germany	2010
University Clinic, Würzburg	14	Germany	2010
Sisters of Charity Hospital, Linz	8	Austria	2011
Rhön Clinic, Hildesheim	10	Germany	2012
Medical School, Hannover	14	Germany	2012

number of patients that are possible for each technology depending on different volumes of daily water consumption per capita. In order to design the system to be installed at the Katharinen Hospital in Stuttgart, a daily consumption of 100 l per patient was assumed, in order to guarantee a minimum comfort level. In comparison, the average daily consumption of 150 l by a single-person-household in Europe can be used as a reference value for this figure.[18] [Eurostat]The initial activity of the water was assumed to be 10^6 Bq/l, whereas the target for final activity was 5 Bq/l. The result depicted in the curves shows the limited extent to which the existing system (equipped with a total volume of 180 m^3) was working. Thus, the old installation was only able to afford six patients accommodated at the nuclear medicine ward.

In order to reach the targeted occupancy of 12 patients, additional 150 m^3 of volume and 2500 m^2 of space would have been necessary, if the Katharinen Hospital had decided to install an additional delay and decay treatment plant. Thanks to BioChroma, it was possible to integrate the new system into the existing plant by using some of the already available tanks. Therefore, ultimately only 625 m^2 more were needed, which equated to a 75% reduction compared with the initial space requirements. Implementing BioChroma in this project enabled the nuclear medicine department to increase its capacity under normal operating conditions by 25 % (i.e., 15 patients). Putting it differently, this technology allows the ward nowadays to accommodate the targeted number of 12 patients at a higher water use rate of 120 l/day instead of 100 l/day. Moreover, the BioChroma system can be “forced” to temporarily increase the processed water volume to the equivalent of that needed by 18 patients (i.e., 50% of the originally planned capacity).

The system installed in Stuttgart is equipped with homogenization pumps that feed two buffer tanks. Biological pretreatment using pulsed oxygen administration takes place in these tanks [Figure 4]. The radioactive waste-water is then pumped at a flow rate of 50 to 120 l/h to the biological treatment unit. Both the sedimentation of the solid matter and the aerobic treatment of the wastewater take place in this biological reactor. Thanks to continuous aeration, the micro-organisms in the activated sludge abate the organic load, while inorganic substances are oxidized to a certain extent. This process produces carbon dioxide and promotes the growth of the biomass (i.e., sludge) in the reactor. This biological treatment process also includes the nitrification of the organic nitrogen, i.e., ammonium is oxidized to nitrate.

The water emerging from the activated sludge reactor is pumped at a pressure of 0.4 and 0.9 bar through two biofilters and a sequence of 24 modified activated carbon filters and ion-exchangers, which are arranged in six modules containing four filters each [Figure 5]. The average concentration at the inlet of the first module is 4,000 Bq/l and is reduced by 90 % to 400 Bq/l at its outlet. The remaining modules gradually reduce the concentration of activity in the water until the final target of 5 Bq/l is reached. One very important aspect of commissioning these modules is the use of water that has been inactivated under pressure (approximately 1 bar) to clean the filters in order to avoid problems of cross-contamination caused by residual air captured in the filters.

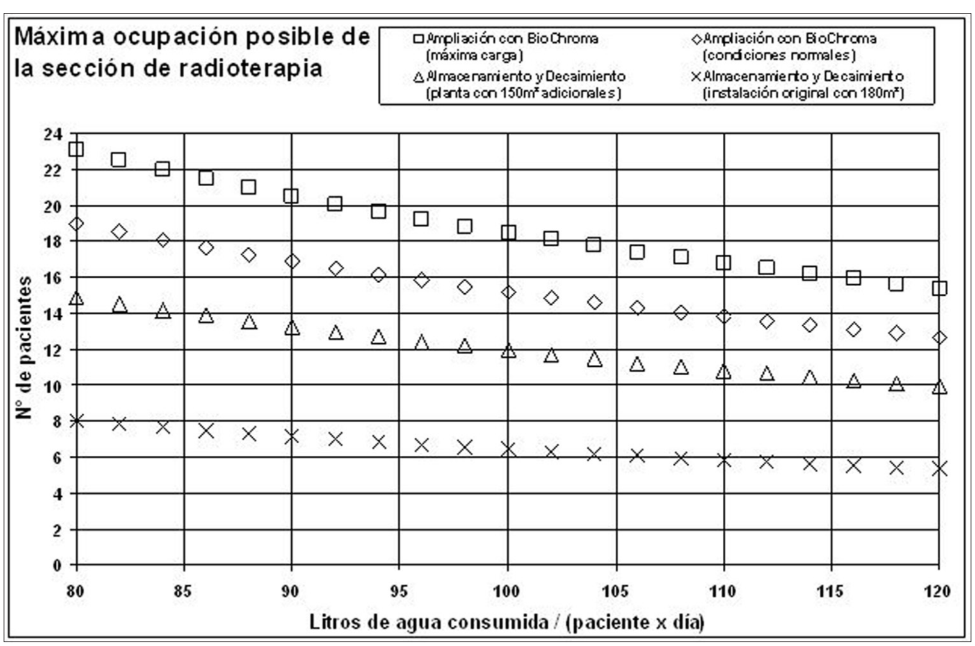

Figure 3: Maximum possible occupancy of the nuclear medicine department by technology and by daily water consumption per patient

Figure 4: Bioreactors with sedimentation chambers (Katharinen Hospital, Stuttgart, Germany) [EnviroDTS]

Figure 5: Overview of the adsorption filter modules with modified activated carbon (Katharinen Hospital, Stuttgart, Germany) [EnviroDTS]

The water which has already been clarified is stored in final buffer tanks, where the quality is monitored prior to discharging the water into the sewage system. A water sample (1 l = 1 litre) is taken in order to measure the final radioactivity of the effluent. Any possible contamination of the sampling vessels or analyzing equipment must be avoided if concentrations of less than 50 Bq/l are to be measured. A calibrated, rectangular multipurpose gamma camera without collimator is used for measuring purposes. The 3/8″ sodium-iodine scintillation crystal can detect gamma radiation of 360 keV with a probability of more than 50%. It is important that sampling vessels have a lead shield at least 5 cm thick. Following this measurement protocol, even levels as low as 2 Bq/l can be detected.

Katharinen Hospital (Stuttgart) – Outcome of implementing the BioChroma system

The effluent treatment plant was successfully commissioned in the middle of 2008. The operation of the system is currently producing very good results with values below the specified limit of 5 Bq/l for the isotope ^{131}I. In addition, ^{90}Y has been reported to be eliminated at the same time.

Over the past 2 years of operation, the wastewater treatment plant has been able to achieve a maximum processing capacity of more than 2,000 l/day, which equates to a nuclear medicine ward with approx. 20 beds. The highest level recorded during the test period (of 180 days after start-up) was a peak of nearly 2,800 l/day. These results have exceeded all expectations of the operators and underline the potential offered by this new technology.

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