^{90}Y Contamination in the Interventional Radiology Suite: VARSKIN Estimation of Skin and Eye Injury and Review of Mitigation Strategies

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Our objective was to demonstrate, through computer simulations, radiation exposure levels from a ^{90}Y contamination event during radioembolization procedures to calculate the radiation doses from various contamination scenarios. We also provide reasonable safety protocols to prevent contamination and minimize radiation exposure during decontamination. **Methods:** Simulations were performed using the computer code VARSKIN+, version 1.0, to determine the amount of radiation exposure resulting from different contamination scenarios. **Results:** The annual radiation dose limit to the skin and the lens of the eye was exceeded within 23 s of exposure to a 44-MBq droplet. Double layers of surgical gloves and level 3 gowns provided some attenuation of radiation from ^{90}Y contamination by reducing the dose rate by 39% and 44%, respectively. Two layers of surgical gloves offered the best ratio of radiation protection without compromising dexterity. **Conclusion:** This study demonstrated that radiation exposures during ^{90}Y spills or contamination events can be considerable. Interventional radiology and nuclear medicine personnel must be mindful of the risks, follow strategies to prevent spills, and be familiar with recommended decontamination procedures for spills in the interventional radiology suite.

Key Words: ^{90}Y; Y90; contamination; occupational radiation exposure; radioembolization; radiation safety

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High doses of radiation are required to achieve the desired results with ^{90}Y radioembolization. The 2 types of ^{90}Y microspheres currently on the market—resin (SIR-Spheres; SIRTEX) and glass (TheraSphere; Boston Scientific)—differ significantly in the company-designated calibration day and resultant specific activity per vial (*1,2*). Vials of glass microspheres can be calibrated to as high as 20 GBq of activity (*1*). Some decay occurs by the time the vial reaches its destination, meaning the highest dose that can be obtained is 18 GBq/vial (*1*). Resin microspheres, on the other hand, were traditionally calibrated to 3 GBq/vial but now can be delivered up to 5 d before calibration to a maximum activity of 11.85 GBq/vial (*2*).

During ^{90}Y radioembolization, many aspects of the delivery process are susceptible to operator error resulting in a spill or contamination, such as improperly spiking the vial or not ensuring that the connections are tight. Numerous incidents of spills have been reported in the literature (*3–5*). Major spills threaten staff safety since they involve significant radiation exposure or personnel contamination.

Interventional radiology (IR) and nuclear medicine team members may not understand the risks and implications of ^{90}Y contamination. This study was conducted to demonstrate radiation exposure levels in contamination events with ^{90}Y spills during radioembolization procedures. Computer simulations were done to calculate the radiation doses incurred from various contamination scenarios. This article also provides spill prevention strategies as well as general procedures, based on the literature, for handling spills and decontaminating skin, clothing, and eyes (*3,4,6–10*).

MATERIALS AND METHODS

Simulations were performed using the computer code VARSKIN+, version 1.0, to assess possible radiation doses incurred from ^{90}Y contamination. VARSKIN has been used extensively to calculate skin doses from radionuclide contamination directly on the skin or on a layer of protective clothing covering the skin. VARSKIN has been validated in multiple studies (*11–13*). For the assessment of effective dose to the skin, an average basal layer depth of 70 μm was used over an area of 1 cm^2 (*14*). The International Commission on Radiological Protection (ICRP) recommends that skin dose be assessed at a depth of 70 μm since the depth of the sensitive basal layer of the epidermis ranges from 50 to 100 μm on most parts of the body (*15*). It is assumed here that only intact skin is affected and that penetration of the contamination in the skin can be neglected. The projection of a 0.05-mL droplet of ^{90}Y was considered to illustrate a contamination event. Contamination events may come from a tubing connection during the dose administration or from the catheter on removal from the patient (*3*). These 2 scenarios typically occur after the vial content has been diluted with flush solution during the administration process. Table 1 illustrates the specific activities of the solution delivered through the microcatheter at the time of administration by considering the 20 mL of diluent used for flushing the vial during administration. The first simulation considered a potential worst-case scenario in which the droplet originated from a

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TABLE 1
Glass and Resin Microsphere Average Activity per Milliliter and per 0.05-mL Droplet of Solution Delivered Through Microcatheter During Dose Administration

Vial activity	Delivery solution average activity per mL (MBq)	Delivery solution average activity per 0.05-mL droplet (MBq)
Glass (GBq/0.6 mL vial)		
1	49	2.5
2	97	5
3	146	7
4	194	10
5	242	12
6	291	15
7	340	17
8	388	19
9	437	22
10	485	24
11	534	27
12	583	29
13	631	32
14	680	34
15	728	36
16	777	39
17	825	41
18	874	44
Resin (GBq/5 mL vial)		
1	40	2
2	80	4
3	120	6
4	160	8
5	200	10
6	240	12
7	280	14
8	320	16
9	360	18
10	400	20
11	440	22

20-mL syringe containing 18 GBq of activity (a 20-GBq vial decayed to the first available treatment day and time). In this situation, the droplet would have 44 MBq of activity. The 0.05-mL droplet is represented by a 3.5-mm-wide cylinder with the thickness and density of glass microspheres (25 μm and 3.3 g/cm^3, respectively) (*1,16*). No level of protection (cover) was provided for the contamination simulations involving direct skin contact and eye contact. For the simulation of hand contamination, a double layer of surgical gloves was added, and no air gap was assumed. The thickness and density of the double glove layer were 0.4 mm and 0.90 g/cm^3, respectively. For the simulation of arm contamination, a level 3 protection surgical gown was added, and again, no air gap was assumed. The gown was 0.5 mm thick and had a density of 0.92 g/cm^3.

The second simulation also considered a worst-case scenario of a 44-MBq droplet, but this time with eye contamination. Dose equivalent values were calculated for the lens of the eye using the computer code VARSKIN+ EyeDose. Again, a droplet of 0.05 mL was considered over a surface area of 1 cm^2. The concern with eye contamination is radiation exposure to the lens of the eye and subsequent development of cataracts over time (*17*). For this experiment, direct contact with the eye was analyzed while considering an average depth of 3 mm of the lens relative to the cornea (*14*).

The third simulation looked at the time required to reach the annual skin dose limit of 500 mSv from a droplet during procedures using vial activities in the range of 1–18 GBq at administration.

The fourth simulation analyzed the levels of radiation exposure with increasing layers of glove protection.

RESULTS

In Figure 1, the skin radiation dose incurred from external contamination by a 44-MBq droplet is represented in a time scale of seconds to simulate a contamination event that is detected immediately and washed off as rapidly as possible. With direct skin contamination, the yearly limit of 500 mSv is reached within 23 s. The gown and surgical gloves provide some protection by attenuating the radiation, thereby reducing the radiation dose to some degree. Still, even with cover protection, the radiation dose remains considerable.

In Figure 2, the skin radiation dose incurred from external contamination by a 44-MBq droplet is represented in a time scale of minutes to simulate a contamination event with delayed detection and decontamination. In this situation, the yearly limit of 500 mSv is surpassed within 1 min even with gown and surgical gloves (cover protection). Less than 2 min of direct skin contact and less than 3 min of contamination over the 0.4-mm gloves and 0.5-mm gown are required to reach the 2,000-mSv threshold at which cutaneous radiation injury can occur.

Protective glasses are an essential component of the personal protective equipment arsenal since they prevent most droplets from reaching the eye. However, in an angled head posture, a droplet can inadvertently reach the eye through a side gap. Figure 3 shows the radiation dose to the lens of the eye in relation to time from contamination by a 44-MBq droplet directly on the eye surface. Exposure time is expressed in seconds since most eye contaminations are felt when they occur and decontamination is not delayed. The ICRP recommends limiting the equivalent dose to the lens of the eye to an average of 20 mSv/y over 5 y (*17*). In Figure 3, we see the 20-mSv limit being reached within 23 s of exposure.

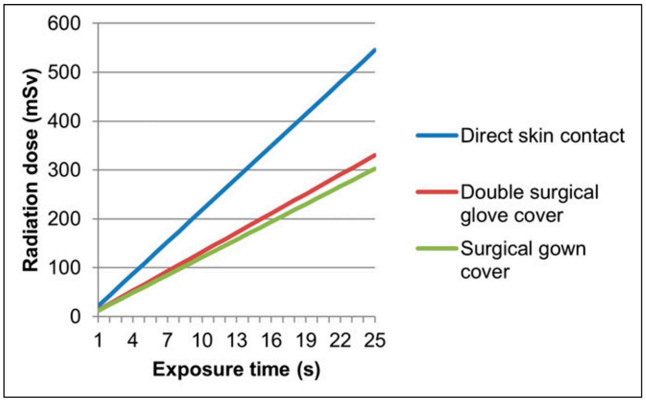

FIGURE 1. Skin radiation dose (mSv) per second of exposure from external contamination by 44-MBq droplet to unbroken skin with and without cover.

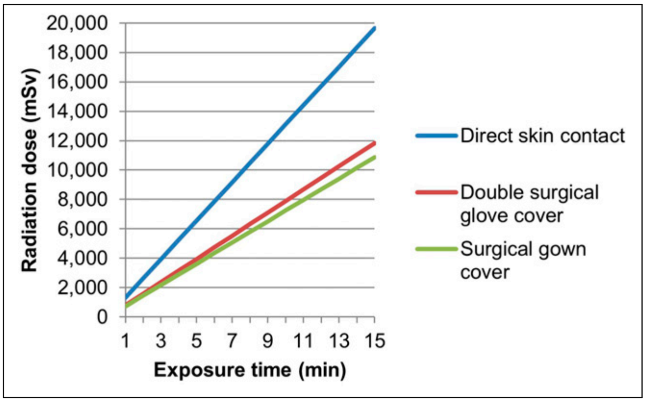

FIGURE 2. Skin radiation dose (mSv) per minute of exposure from external contamination by 44-MBq droplet to unbroken skin with and without cover.

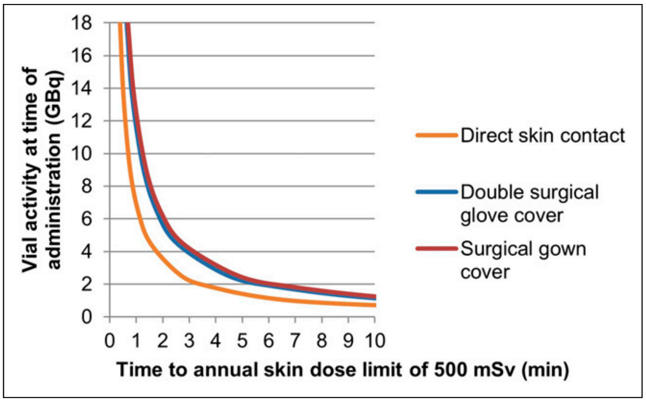

FIGURE 4. Time to annual skin dose limit of 500 mSv from external contamination by single 0.05-mL droplet to unbroken skin with and without cover from range of vial activities at time of administration.

Most ^{90}Y radioembolization procedures will require less than 18 GBq; therefore, Figure 4 illustrates the time required to reach the annual skin dose limit from a contamination droplet from the range of possible activities at administration. For ^{90}Y procedures using more than 2 GBq, less than 4 min of direct skin exposure to a 0.05-mL contamination droplet will surpass the annual skin dose limit of 500 mSv.

The external dose rate from a droplet of 1 MBq to unbroken skin is listed in Table 2. A single layer of surgical glove cover reduced the dose rate by 26%, whereas a double glove cover provided a dose rate reduction of 39%, compared with bare skin. Similarly, a surgical gown cover offered a 44% dose rate reduction. The exposure times to receive the maximum annual equivalent dose of 500 mSv and the investigational level of 50 mSv from a 1-MBq droplet are also listed in Table 2. On average, contamination from a 1-MBq droplet will take 2.5 min to reach the investigational level and 25.2 min to reach the maximum annual dose limit. One could use these findings to extrapolate to any droplet activity, that is, a 2-MBq droplet will take half the time to cross the same threshold and so on.

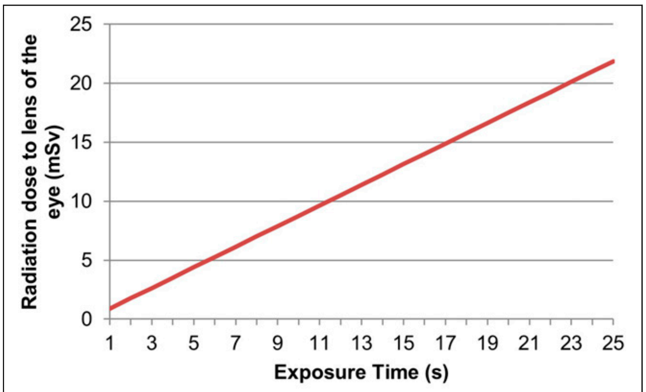

FIGURE 3. Radiation dose (mSv) to lens of eye per second of exposure from contamination by 44-MBq droplet directly on eye surface.

Figure 5 demonstrates the dose rate reduction afforded by increasing layers of gloves. The most significant dose rate reductions are seen with the first 2 layers. Subsequent layers offer a diminishing rate of return.

DISCUSSION

Acute exposure to a large external dose of β-radiation can lead to cutaneous radiation injury resulting in deterministic effects such as erythema, inflammation, and desquamation (*18–21*). From a radiation protection context, moist desquamation of the skin is the reaction to be prevented after acute exposure of the skin to ionizing radiation (*21*). Moist desquamation is associated with the loss of reproductive integrity of stem cells in the basal layer and may result at approximately 3–6 wk after exposure (*21*). The approximate threshold single dose for this reaction of the skin to ionizing radiation from a β-emitter such as ^{90}Y is 17.5−25 Gy (*21*). Acute radiation doses greater than 0.5 Gy to the lens of the eye can cause lens opacities that may go unnoticed for several years (*17*).

The simulations in this study demonstrate that contamination from a single 0.05-mL droplet can lead to significant skin doses, especially during high-dose procedures. Personal protective equipment such as surgical gloves and gowns must not be relied on as a means of shielding since they provide only partial attenuation of the radiation from direct contamination. The ICRP recommends wearing double gloves during selective internal radiation therapy procedures to allow for quick removal of a contaminated outer glove with a gloved hand (*19,20*). This technique can greatly reduce radiation exposure in the event of contamination by minimizing exposure time. This study demonstrated that adding additional pairs of gloves beyond the recommended 2 pairs offers diminishing returns in protection. One must also consider that extra pairs of gloves can reduce dexterity, potentially resulting in longer procedure times, ultimately increasing radiation exposure risk to both patients and staff. These results concur with current practice and recommendations by the ICRP of wearing 2 layers of surgical gloves when handling ^{90}Y (*19,20*).

TABLE 2
External Dose Rate from Droplet of 1 MBq of ^{90}Y to Unbroken Skin

Geometry	Dose rate (mSv min^{-1}/MBq)	Exposure time (min) to receive maximum annual equivalent dose (500 mSv)	Exposure time (min) to receive investigational/action level of 10% of maximum annual equivalent dose (50 mSv)
No cover	28.7	17.4	1.7
Single surgical gloves	21.3	23.5	2.4
Double surgical gloves	17.5	28.6	2.9
Surgical gown	16	31.3	3.1

Gowns offer similar protection by limiting exposure time in cases of contamination since they can be removed quickly. However, parts of the body remain vulnerable to direct contamination, such as the face and neck. The eyes are especially vulnerable considering the small amount of radiation required to cause detrimental effects to the lens. Accumulation of radiation to the lens of the eye over time can lead to the formation of cataracts (*17*). To mitigate this risk, the ICRP recommends limiting exposure to less than 20 mSv/y over 5 y (*17*). Wearing a full-face shield would greatly reduce the risk of contaminating exposed skin and eyes. In many cases, the annual skin dose limit of 500 mSv can quickly be surpassed since decontaminating the skin requires a certain amount of time to complete. Limiting exposure time through immediate decontamination should be a priority after the detection of contamination. Frequent monitoring could also offer a significant reduction in radiation exposure. Consider, for example, glove contamination by a droplet that goes unnoticed early in the procedure. Such a droplet would dry in a matter of seconds. If monitoring were not performed until the end of the procedure, after gloves had been removed, the interventionalist would not realize that contamination had occurred. ^{90}Y radioembolization procedures can last 1 h or more; therefore, a significant amount of radiation exposure would have occurred. To limit contamination exposure time, IR staff is subject to periodic monitoring during the procedure and monitoring on exiting the IR suite. Monitoring allows clean-up of contamination as soon as it occurs and control of the accumulated radiation dose to staff. The potential for contamination is particularly high when administering the dose, removing the catheter, and disposing of it in radioactive waste storage. The department radiation safety officer (RSO) or radiation safety support personnel on-site can perform the monitoring task. A survey meter with a Geiger–Mueller pancake detector is appropriate to monitor or frisk for contamination.

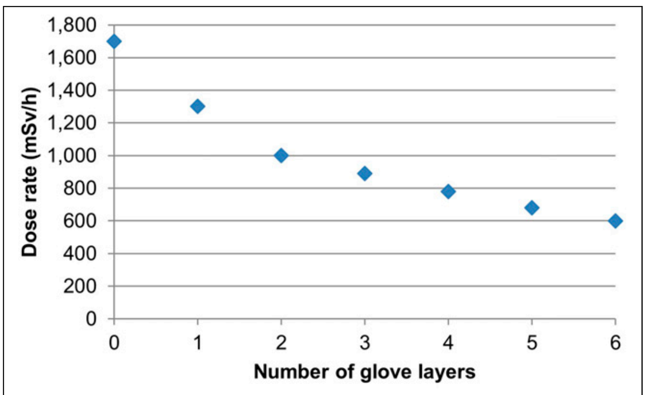

FIGURE 5. Dose rate (mSv/h) to 1 cm^2 of unbroken skin from 1-MBq (0.05 mL) droplet of ^{90}Y in relation to number of layers of 0.2-mm-thick surgical gloves covering unbroken skin.

The most effective way to limit contamination and unnecessary radiation exposure is to prevent accidental spills from occurring. Several strategies can be implemented to reduce their occurrence (*3,4*). All tubes and catheters can be flushed with water or saline for injection before manual manipulation of ^{90}Y. Before the infusion starts, the tightness of connections can be checked, the tubing and connections can be checked for leaks, the catheter can be checked for kinks, and proper spiking of the septum of the dose vial with the needle injector can be ensured. Setup instructions can be read out loud and followed by the physicians. The procedure can be stopped if the pressure gauge indicates readings above the trigger levels, if the catheter position changes, or if a significant number of microspheres are detected in the vent line or empty vial. When the catheter is removed from the patient, the tip can be wrapped in gauze or a small towel to control contamination, and the physician removing the catheter can avoid touching any other materials until cleared by the RSO.

Every team member involved in ^{90}Y radioembolization should be well versed in handling a spill or contamination. Instructions for emergency procedures should be made available in every spill kit if there is any doubt about how to proceed. IR suites should have emergency equipment readily available for handling spills. The U.S. Nuclear Regulatory Commission offers a list of items that should be included in a spill kit and sample guidelines on how to proceed after a minor and major spill, which can be found in Figure 6 (*10*). Minor contamination events are those in which tiny drops or easily cleaned spills are contained on absorbent pads and pose no significant hazards to workers. In contrast, a major decontamination protocol should be considered whenever there is more than 37 MBq of ^{90}Y activity involved, when the spill cannot be easily contained, or when reasonable efforts to decontaminate are unsuccessful (*10*).

General safety procedures to handle spills.

Spill kit items

- Disposable gloves
- Disposable lab coats
- Disposable head coverings
- Disposable shoe covers
- Roll of absorbent paper with plastic backing
- Masking tape
- Plastic trash bags with twist ties
- "Radioactive material" labeling tape
- Marking pen
- Prestrung "Radioactive Material" labeling tags
- Contamination wipes
- Instructions for "Emergency Procedures"
- Clipboard with a copy of Radioactive Spill Report Form
- Pencil
- Appropriate survey instruments, including batteries

Minor spills

1. Notify persons in the area that a spill has occurred.
2. Prevent the spread of contamination by covering the spill with absorbent paper.
3. Wear gloves and protective clothing, such as a lab coat and booties, and clean up the spill using absorbent paper. Clean up the spill by wiping from the perimeter of the spill to the center of the spill.
4. Carefully fold the absorbent paper with the clean side out and place in a bag labeled "caution radioactive material" for transfer to a radioactive waste container. Also, put contaminated gloves and any other contaminated disposable material in the bag.
5. Survey the area with an appropriate low-range radiation detection instrument. Survey for removable contamination to ensure contamination levels are below trigger levels. Survey the area around the spill.
6. Continue to clean up the spill and re-survey until radiation levels and removable contamination are below trigger levels.
7. Survey hands, clothing, and shoes for contamination prior to leaving the area.
8. Report the incident to the RSO promptly.
9. Cooperate and follow the instructions of the RSO and the RSO staff (e.g., criteria for returning to the work area, investigation of root cause, provision of requested bioassay samples, decontamination techniques, surveys, requested documentation).

Major spills

1. Clear the area. Notify all persons not involved in the spill to vacate the room.
2. Prevent the spread of contamination by covering the spill with absorbent paper labeled "caution radioactive material," but do not attempt to clean it up. To prevent further spread of contamination, clearly indicate the boundaries of the spill and limit the movement of all personnel who may be contaminated.
3. Shield the source only if it can be done without further contamination or a significant increase in radiation exposure.
4. Close the room and lock or otherwise secure the area to prevent entry. Post the room with a sign to warn anyone trying to enter that a spill of radioactive material has occurred.
5. Notify the RSO immediately.
6. Survey all personnel who could possibly have been contaminated. Decontaminate personnel by removing contaminated clothing and flushing contaminated skin with lukewarm water, then washing with mild soap. Document personnel decontamination efforts.
7. Cooperate and follow the instructions of the RSO and the RSO's staff (e.g., criteria for returning to the work area, investigation of root cause, provision of requested bioassay samples, decontamination techniques, surveys, requested documentation).

FIGURE 6. General safety procedures to handle spills. (Adapted from (*10*).) Standalone downloadable version of this figure is available as supplemental file at http://tech.snmjournals.org.

The following are general guidelines that can be used to reduce radiation exposure in the event of personnel contamination (*6–9*):

Contaminated Clothing

Wearing gloves, carefully remove the contaminated clothing, rolling it outward away from the skin, trapping the contaminant material inside. Place contaminated clothing in a plastic bag. Seal and label the bag appropriately for special waste disposal. Survey the skin for contamination and decontaminate if necessary. Contact the RSO and follow further instructions.

Contaminated Skin

Flush the affected area with lukewarm water. Avoid hot or cold water. Wash the area gently with nonabrasive soap and water, being careful not to irritate the skin. Start from the periphery of the contaminated area and move toward the center. Survey the affected area. If contamination persists, repeat the decontamination efforts. Contact the RSO and follow further instructions.

Contaminated Eye

Use local eyewash or a saline eyewash bottle as soon as possible. Monitor the hand for radioactive contamination; if clean, use the thumb and index finger to open the eyelids. If the fingers are contaminated, ask for assistance to hold the eyelids open. Irrigate the eye thoroughly, ensuring that water runs from the inside edge of the eye outward to prevent cross-contamination of the face and the other eye. Use a sink or plastic bowl to collect the water and prevent the spread of contamination if possible. Monitor for contamination and, if necessary, repeat the flush. Contact the RSO and follow further instructions.

Skin decontamination should always be done using lukewarm water since hot water opens the pores, allowing contamination to enter, and cold water closes the pores, trapping contamination (*8*). Washing should be gentle, as vigorous rubbing may cause surface damage to the skin, permitting the material to enter the body. A brush should never be used because it can damage the skin; however, a soft cloth may be used if applied gently. Special care should be taken with facial contamination to avoid having the material enter the eyes, ears, nose, mouth, or any wounds. Cleaning and monitoring should be repeated until all residual contamination has been removed. If contamination remains, further abrasive actions may be taken, but only after discussion with the RSO.

During the preparation and administration of the ^{90}Y microspheres, every precaution should be taken to minimize the risk of contamination. Staff should don the following protective equipment: scrubs, gown, mask, surgical cap, double shoe covers, gloves, lead apron, thyroid shield, and eye and face protection. Because goggles alone leave the face unprotected, a full face shield that curves around the sides of the face is preferred (*19*). It is recommended that staff manipulating the radioactive material use a double layer of gloves to allow the removal of a contaminated outer glove with a gloved hand (*19,20*). A radiation survey meter and spill kit should be available before the radioactive substance is in the procedure room (*10*). Hands should be checked for contamination immediately after the dose-drawing process or any manipulation during administration to prevent delays in decontamination if contamination occurs.

Every worker involved with ^{90}Y radioembolization should be well versed in decontamination procedures because spills usually occur quickly and unexpectedly. It would be reasonable to retrain staff at least annually, through simulated exposure events, to enhance decontamination response times. Decontamination procedures must remain top-of-mind to ensure that in the event of a contamination, decontamination is performed quickly and efficiently. When contamination occurs, time is of the essence. Decontamination must be done promptly to reduce radiation exposure. Knowing the radiation doses that one could receive from a contamination event can help increase vigilance. But even more critical is knowing the best course of action to decontaminate after a spill.

CONCLUSION

This study highlighted contamination risks involved with ^{90}Y radioembolization procedures. IR and nuclear medicine staff need to be informed and prepared to respond quickly when a spill occurs. Contamination events should never be taken lightly, as radiation exposure can be significant. Annual skin dose limits can be surpassed within seconds from contamination by a tiny droplet. Every effort should be made to prevent spills from occurring, and precautions should always be taken to reduce radiation exposure in the event of a spill.

KEY POINTS

QUESTION: What radiation exposure levels result from a ^{90}Y contamination event during radioembolization procedures?

PERTINENT FINDINGS: Contamination during high-dose procedures can surpass the annual skin dose limit of 500 mSv within several seconds, and cutaneous radiation injury can occur within minutes, even if the contamination occurs over the cover protection of surgical gloves or gown. In a contamination event, wearing a double layer of surgical gloves reduces radiation exposure by 39%, and wearing a level 3 gown reduces radiation exposure by 44%, compared with no cover protection.

IMPLICATIONS FOR PATIENT CARE: Contamination from a single droplet during ^{90}Y radioembolization procedures can lead to significant radiation exposure. IR and nuclear medicine personnel must be mindful of the risks, follow strategies to prevent spills, and be familiar with recommended decontamination procedures.

DISCLOSURE

This research was funded by the Dalhousie Medicine New Brunswick Research in Medicine Summer Studentship. Robert J. Abraham is the chief medical officer, a shareholder, and a patent holder of ABK Biomedical Inc. No other potential conflict of interest relevant to this article was reported.

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