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TECHNICAL NOTE

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Radiation Safety for the NOMAD™ Portable X-Ray System in a Temporary Morgue Setting*

ABSTRACT: The purpose of this study was to determine the radiation levels resulting from leakage and scatter encountered by the forensic dental personnel using the Nomad™ at St. Gabriel, LA, following Hurricane Katrina. Using a Keithley Radiation Survey Meter and Lucite head phantom, radiation levels were measured at various distances and angles from the Nomad™ corresponding to the positions occupied by the dental personnel at St. Gabriel. The measurements were used to approximate the maximum total radiation dose from the Nomad to each team member for a 2- and a 4-week deployment. The results show that the maximum scatter radiation dose to any team member was 4.4 μR per X-ray or 0.253 millisieverts (mSv) for a 2-week deployment and 0.506 mSv for a 4-week deployment. Therefore, the leakage and scatter radiation dose from the Nomad™ was insignificant compared with established radiation safety guidelines of 50 mSv per year for all team members.

KEYWORDS: forensic science, forensic odontology, Nomad™, radiation safety

The forensic odontologists who responded to the need for identification of the victims of Hurricane Katrina from New Orleans were pleased to find a new tool available to them at the temporary morgue site at St. Gabriel, LA. The new tool was a battery-powered, portable, hand-held X-ray unit called the Nomad™ (Fig. 1). Sold and distributed by Aribex, Inc., Orem, Utah, the units performed exceptionally well. They proved to be a very valuable piece of equipment that had the portability and versatility required in the somewhat austere conditions that typically exist in a temporary morgue environment. The objective of this study was to determine the exposure output and scatter characteristics of the Nomad™ Portable X-ray Unit for a given period of time and the prospective radiation dose to the operator, assistant, and computer operator at various body locations and angles from the beam, as encountered in the morgue at St. Gabriel, LA, following Hurricane Katrina.

The radiation safety characteristics of the Nomad™, reported by D. Clark Turner, Donald K. Kloos, and Robert Morten (1) for the operator and the patient, were provided by Aribex in their promotional material. Their findings confirm that radiation levels for the patient and operator are well within established radiation safety guidelines. However, their report did not consider radiation levels for additional personnel that were required to be in close proximity to the Nomad™ in a temporary morgue setting. In the morgue, the patient cannot hold an X-ray film or computer sensor in position, requiring a second team member, the assistant, to perform that function. The morgue operation in St. Gabriel also made use of digital X-rays requiring a third person be present to operate the computer. Early in the operation at St. Gabriel, there were as many as three dental stations, each with three-person forensic dental teams operating simultaneously within the dental section. As professionals who frequently deal with radiation, the issue of radiation safety was a concern to the team leaders because of the close proximity of the dental teams. There were no dosimeter badges available to measure the amount of radiation to which the team members may be exposed. To address the issue, it was decided that a coin would be taped to a dental periapical X-ray film. Each member was provided a film with a coin attached and wore the film for a period of 7 days under the Tyvek suit whenever they were in the morgue. At the end of 7 days, the films were developed. None of the films showed the image of the coin, indicating that none of the team members was exposed to enough radiation to expose the film. However, considering the number of X-rays taken at St. Gabriel, there was a need to quantify the radiation levels more precisely at various distances and locations to confirm that radiation dose levels to all personnel in the morgue were within the recommended radiation safety levels.

Methods

A polymethyl methacrylate (Lucite) head phantom (Fig. 2) (Dupont, Inc., Wilmington, DE) was used to approximate a human head for measurements from 0° to 90°, and two Lucite rectangular blocks were used for readings from 105° to 180° to approximate the mandible and maxilla. The head phantom (Fig. 2) has a diameter of 16 cm and the blocks have a thickness of 5.1 cm each, 10.2 cm in total. Both have a density of 1.19 (±0.01 g/cm^3), so multiplying the density to each thickness equals about 19.0- and 12.1-cm equivalent tissue thickness for the head phantom and Lucite blocks, respectively. All exposures were carried out with the removable external lead ring in place at the end of the Nomad™ cone (Fig. 3). Exposures were taken through the Lucite phantom and measured using the Keithley Radiation Survey Meter (Keithley Instruments, Inc., Cleveland, OH) (Fig. 4) in the integrate mode on a scale of 0–200 micro-Roentgens (μR). The Nomad™ was set to 0.12 sec, 60 kVp, and 2.3 mA for each X-ray exposure, the same settings that were typically used at St. Gabriel. Readings were taken in a horizontal plane at angles of 0° to 180° in 15°-increments (Fig. 5). 0° was directly behind the Nomad™ and 180° was directly in front of the cone in direct line with the radiation beam.

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FIG. 1—*The Nomad™ is a hand-held, portable X-ray unit that is powered by rechargeable batteries. It proved to be a very valuable tool in the operation at St. Gabriel.*

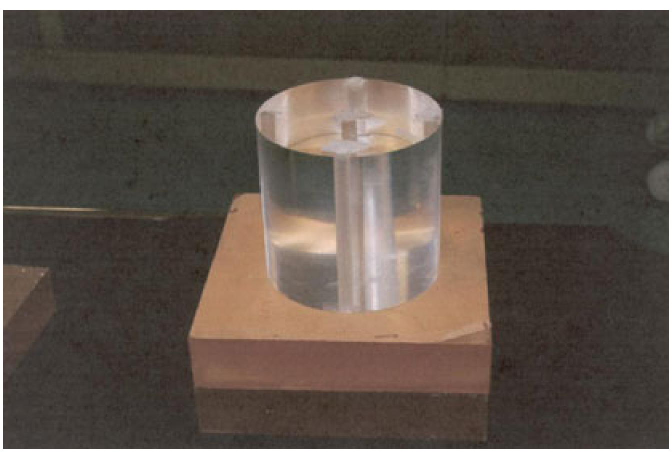

FIG. 2—*Polymethyl methacrylate (Lucite) phantom (Dupont, Inc., Wilmington, DE).*

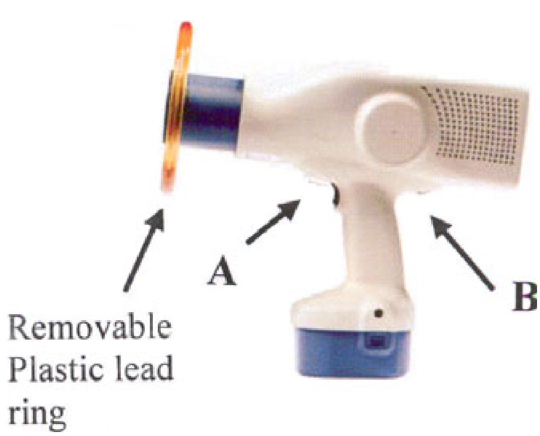

FIG. 3—*The lead ring proved to be very important for shielding from scatter radiation. Operation without the lead ring in place resulted in radiation measurements as much as 10 times higher.*

The operator occupied what the Nomad™ promotional material called the "zone of significant occupancy" (Fig. 6) from 0° to *c*. 35°. Readings were taken at the operator's head, chest, and waist

FIG. 4—*Keithley Integrating Radiation Survey Meter, Model 36150 (Keithley Instruments, Inc., Cleveland, OH).*

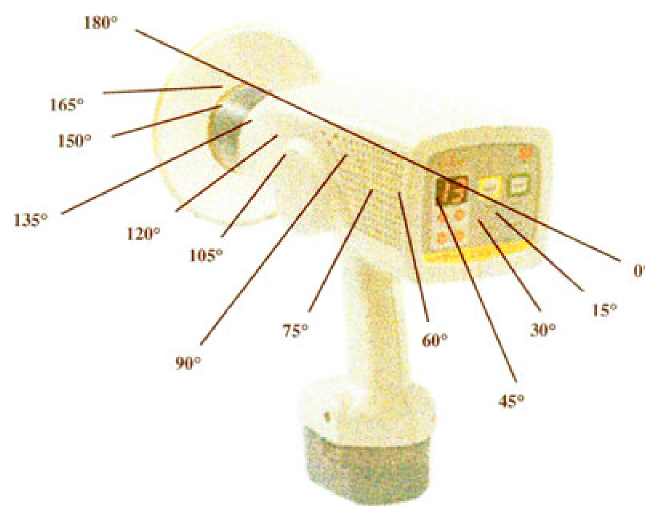

FIG. 5—*Horizontal measurements were taken in 15° increments from 0° to 180° at a distance of 0.46 and 1 m at three different vertical positions corresponding to the height of the head, chest, and waist of the assistant and operator.*

at a horizontal distance of 0.46 m away from the phantom at the 0° angle. Additionally, the operator's hand dosage measurements were taken at points "A" and "B" (Fig. 3), front and back respectively, of the Nomad™ handle to check for radiation leakage. For the assistant, measurements were taken at a horizontal distance of 1 m (Fig. 7) corresponding to the exposure to the assistant's head, chest, and waist. A vertical distance of 1.5 m from the floor was used as the head height, 1.33 m from the floor as the chest height, and 0.93 m from the floor as the waist height. Measurements were taken at 45° and 90° for the computer operator at a horizontal distance of 1.5 m away from the phantom and a height of 0.93 m. A reading at the waist height was the only height measurement required due to the computer operator being seated at the computer while the exposure is taking place.

Results

The radiation levels as detected by the Keithley Radiation Survey Meter are tabulated in Table 1. These measurements represent the amount of radiation in *micro*-Roentgens per exposure at the various locations. Using these measurements, the dose to the

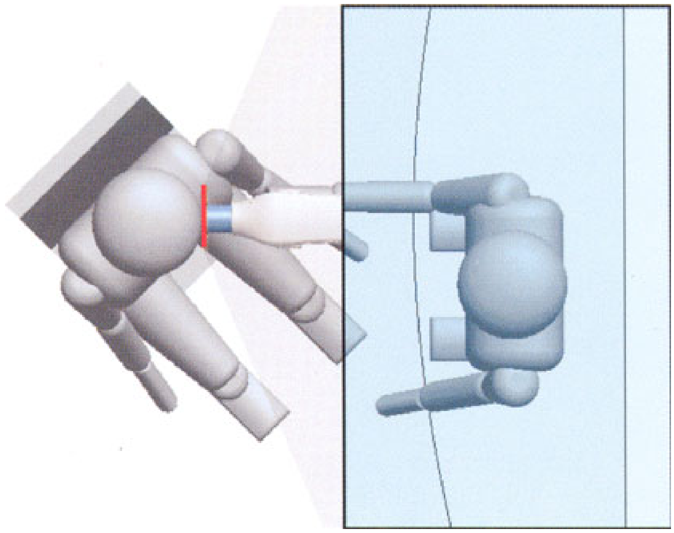

FIG. 6—*"Zone of Significant Occupancy," Aribex, Inc. Used by permission.*

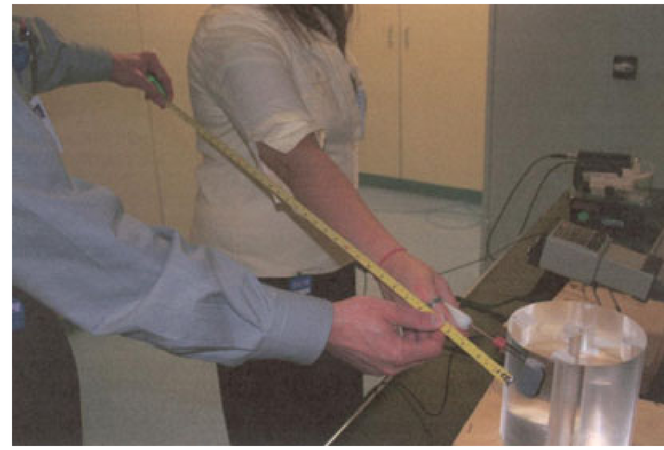

FIG. 7—*Measurements were taken at a horizontal distance of 1 m for the assistant's head, chest, and waist.*

operator, assistant, and computer operator deployed to St. Gabriel was calculated based on operation of the Nomad™ unit for one 12-day period (Table 2) and two 12-day periods (Table 3). The number of exposures was calculated based on each dental team averaging 30 examinations per shift, 16 exposures per victim, and working 12 complete 12-h shifts during a 2-week deployment. The results show that the maximum radiation dose as a result of scatter radiation was to the assistant's chest when the assistant occupied the position at 60° to the Nomad™ or 30° behind the plane of the lead ring. At this location, the assistant's chest was exposed to 4.4 μR of radiation per X-ray (Table 1) or 0.253 millisieverts (mSv) per 5760 X-rays for a 2-week deployment (Table 2). The radiation measurements for all angles and locations can be found in Tables 1, 2, and 3. It should be noted that in our study, we found that having the lead ring properly positioned on the end of the Nomad™ cone was essential. Removing the lead ring resulted in

TABLE 1—*Radiation dose per exposure.*

			Dose in μR for Given Angle												
Person	Location	Distance (m)	0	15	30	45	60	75	90	105	120	135	150	165	180
Assistant	Waist	1	0.3	0.7	0.9	2.1	3.0	2.7	2.4	0.6	1.1	1.5	2.3	3.2	3.9
	Chest	1	0.5	1.1	1.0	2.9	4.4	3.3	2.9	1.1	1.2	2.2	2.8	3.3	33.5
	Head	1	0.7	0.9	1.8	3.0	4.0	2.9	2.3	1.1	1.2	2.0	2.2	2.7	3.6
Operator (body)	Waist	0.46	1.5												
	Chest	0.46	2.1												
	Head	0.46	3.4												
(hand)	A		2.3												
	B		1.0												
Computer	Waist	1.5				0.3			0.4						

Exposure conditions: 60 kVp, 2.3 mA, 0.12 sec (0.276 mAs).
Waist height from floor, 0.93 m; chest height from floor, 1.33 m; head height from floor, 1.5 m.

TABLE 2—*Radiation dose for 2-week deployment.*

			Dose in mSv for Given Angle												
Person	Location	Distance (m)	0	15	30	45	60	75	90	105	120	135	150	165	180
Assistant	Waist	1	0.016	0.037	0.048	0.111	0.159	0.143	0.127	0.032	0.058	0.079	0.122	0.170	0.207
	Chest	1	0.026	0.058	0.053	0.154	0.253	0.175	0.154	0.058	0.064	0.117	0.148	0.175	1.775
	Head	1	0.037	0.048	0.095	0.159	0.212	0.154	0.122	0.058	0.064	0.106	0.117	0.143	0.191
Operator (body)	Waist	0.46	0.079												
	Chest	0.46	0.111												
	Head	0.46	0.180												
(hand)	A		0.122												
	B		0.053												
Computer	Waist	1.5				0.016			0.021						

Exposure conditions: 60 kVp, 2.3 mA, 0.12 sec (0.276 mAs).
Waist height from floor, 0.93 m; chest height from floor, 1.33 m; head height from floor, 1.5 m.
16 exposures/patient × 30 patients/day × 12 day period = 5760 exposures.

TABLE 3—*Radiation dose for 4-week deployment.*

Person	Location	Distance (m)	Dose in mSv for Given Angle												
			0	15	30	45	60	75	90	105	120	135	150	165	180
Assistant	Waist	1	0.032	0.074	0.096	0.222	0.318	0.286	0.254	0.064	0.116	0.158	0.244	0.340	0.414
	Chest	1	0.052	0.116	0.106	0.308	0.506	0.350	0.308	0.116	0.128	0.234	0.296	0.350	3.55
	Head	1	0.074	0.096	0.190	0.318	0.424	0.308	0.244	0.116	0.128	0.212	0.234	0.286	0.382
Operator (body)	Waist	0.46	0.158												
	Chest	0.46	0.222												
	Head	0.46	0.360												
(hand)	A		0.244												
	B		0.106												
Computer	Waist	1.5				0.032			0.042						

Exposure conditions: 60 kVp, 2.3 mA, 0.12 sec (0.276 mAs).
Waist height from floor, 0.93 m; chest height from floor, 1.33 m; head height from floor, 1.5 m.
16 exposures/patient × 30 patients/day × 12 day period × 2 periods = 11,520 exposures.

radiation readings almost 10 times higher than measurements with the ring in place.

Discussion

The risks and benefits of ionizing radiation have been well established over the past several decades. The National Council on Radiation Protection and Measurements (NCRP), established by Congress in the mid-1960s, is responsible for collecting and analyzing worldwide data regarding radiation safety. Based on their analysis, the NCRP develops safety guidelines that establish annual maximum permissible dose (mpd) levels. According to the NCRP, every day in the United States, we are exposed to *c.* 3.65 mSv of naturally occurring radiation from our environment. The maximum permissible dose for occupational exposure established by the NCRP is currently 50 mSv (2). This means that the NCRP has determined that an individual who works with ionizing radiation can be exposed to up to 50 mSv of radiation annually in performing their occupation without increasing the risk for developing radiation-related illnesses. This exposure is in addition to the 3.65 mSv from the environment. The annual dose limit for a radiation worker's hand cannot exceed 500 mSv.

In our study, it was estimated that *c.* 5760 exposures would be the maximum number of radiographs that could have been taken by any dental team while on a 2-week deployment at St. Gabriel. This number was attained by assuming an average of 16 exposures per patient, 30 patients per day over a 12-day period and used as the standard for all calculations. It was noted that the measurements obtained in our study for the operator were similar to the exposure values quoted in the NOMAD™ literature of 1 mR of operator dose for 138 mAs exposure. From phantom measurements, the maximum dosage reading overall was recorded at the assistant's chest 1 m away and directly in front of the beam (180°), a position that no one on the dental team occupied while the digital sensors were being exposed to radiation. The next highest reading outside the primary beam was for the assistant's chest 1 m away and 60° from the beam. Even if one member of the dental team remained as the assistant for their entire deployment and positioned at 60° for every exposure, the 4.4 μR per exposure (Table 1) would accumulate to only 0.253 mSv (Table 2) for the entire deployment. Therefore, 0.253 mSv is the maximum radiation dose that any member of the dental team could have received in a 2-week deployment. Compared with the annual occupational dose limit of 50 mSv, the radiation exposure to the assistant was insignificant. The radiation dose to the operator and computer operator was even less.

Even though the risk to the dental personnel was extremely low at St. Gabriel and posed no health risk, radiation safety should never be taken for granted. Every precaution should be taken to limit exposure to the operator, assistant, and computer operator by utilizing proper radiation safety procedures whenever and to whatever extent possible (3–5). As Low As Reasonably Achievable (ALARA) is the approach that radiation safety experts take to provide the safest possible radiation environment. One way to ensure ALARA is to follow appropriate Time-Distance-Shielding methods. Set exposure time to the smallest value that will still provide accurate results, increase the distance between teams working simultaneously as much as possible, and shield oneself whenever the equipment is provided and plausible. Also, if available, radiation badges are a valuable tool to monitor each team member's accumulated exposure over time.

Conclusion

As Forensic Odontologists, circumstances in a morgue setting like St. Gabriel often require that dental personnel remain in relatively close proximity to the radiation source to obtain postmortem radiographs. ALARA can be achieved when using the Nomad™ by never operating the Nomad™ without the lead ring in place, keeping the exposure time as short as possible, using digital radiography or conventional "E" speed film, having the assistant share the "zone of significant occupancy" with the operator as much as possible, and rotate duties during long deployments. St. Gabriel was the first large-scale domestic use of the Nomad™ and the amount of scatter radiation associated with its use was largely unknown to the dental personnel. However, the Nomad™ proved to be very valuable in accomplishing the task at hand and very safe, posing no significant health risk to any of the dental personnel at St. Gabriel.

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