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ORIGINAL ARTICLE

Investigation of conventional diagnostic X-ray tube housing leakage radiation using ion chamber survey meter in Mizoram, India

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Leakage radiation that transmitted the protected X-ray tube housing was measured and compared with national and international safety standard. To the best of the authors' knowledge, no tube housing leakage measurement has been done so far in the present study area. The authors considered all the conventional diagnostic X-ray units in Mizoram, India. Ion chamber survey meter was used to measure leakage radiation and it was placed at 5 different positions (left, right, front, back, top) of the X-ray tube. Measurements were done at 1 m focus-to-detector distance by projecting X-ray tube vertically downward with collimator diaphragms closed completely. SPSS statistics for windows, version 17.0 (SPSS, Inc., Chicago, IL, USA) was used to derived mean, standard error of the mean etc. The tube housing leakage exposure rates ranged between 0.03 mRh^{-1} and 500 mR h^{-1}; among the 5 positions, rate measured in the front direction has the highest mean at 41.61±8.63 mR h^{-1}; whereas the top has the lowest 4.57±1.16 mRh^{-1}. Tube housing radiation level ranged from 0.01 to 58 mR in one hour. Leakage radiation was minimum at the top position of the tube and maximum in the front direction. All the equipment were in compliance with national and international standard norms, the highest leakage radiation level was 50.43% of the safety limit.

Keywords: Conventional diagnostic X-ray, tube housing leakage radiation, radiation protection, survey meter.

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Introduction

Diagnostic X-ray imaging is one of the basic and fastest way for physicians to view the internal organs and structures of the human body, which has no proper substitute till today.[1] The rapid increase in demand of X-ray application has led to unnecessary patient exposure.[2] On the other hand, provision of high-quality healthcare services is the main purpose of using medical devices.[3] In addition, medical exposures are the most considerable source of ionizing radiation not only to the patients and radiation workers but also to the general public. So, X-ray diagnosis is the most important field, exposures resulting from these examinations have to be reasonably controlled to decrease health risk.[4] It is well-known that the interaction of accelerated electrons with matter in the atomic level generates X-ray photons. When photons interact with matter, they transferred their energy to the electrons contained in matter.[5] Matter absorbs or change energy and/or direction of photon motion.[6] Unlike charged particles, photons have no associated range that limits their distance of travel. There is always a finite probability that some incident photons will get

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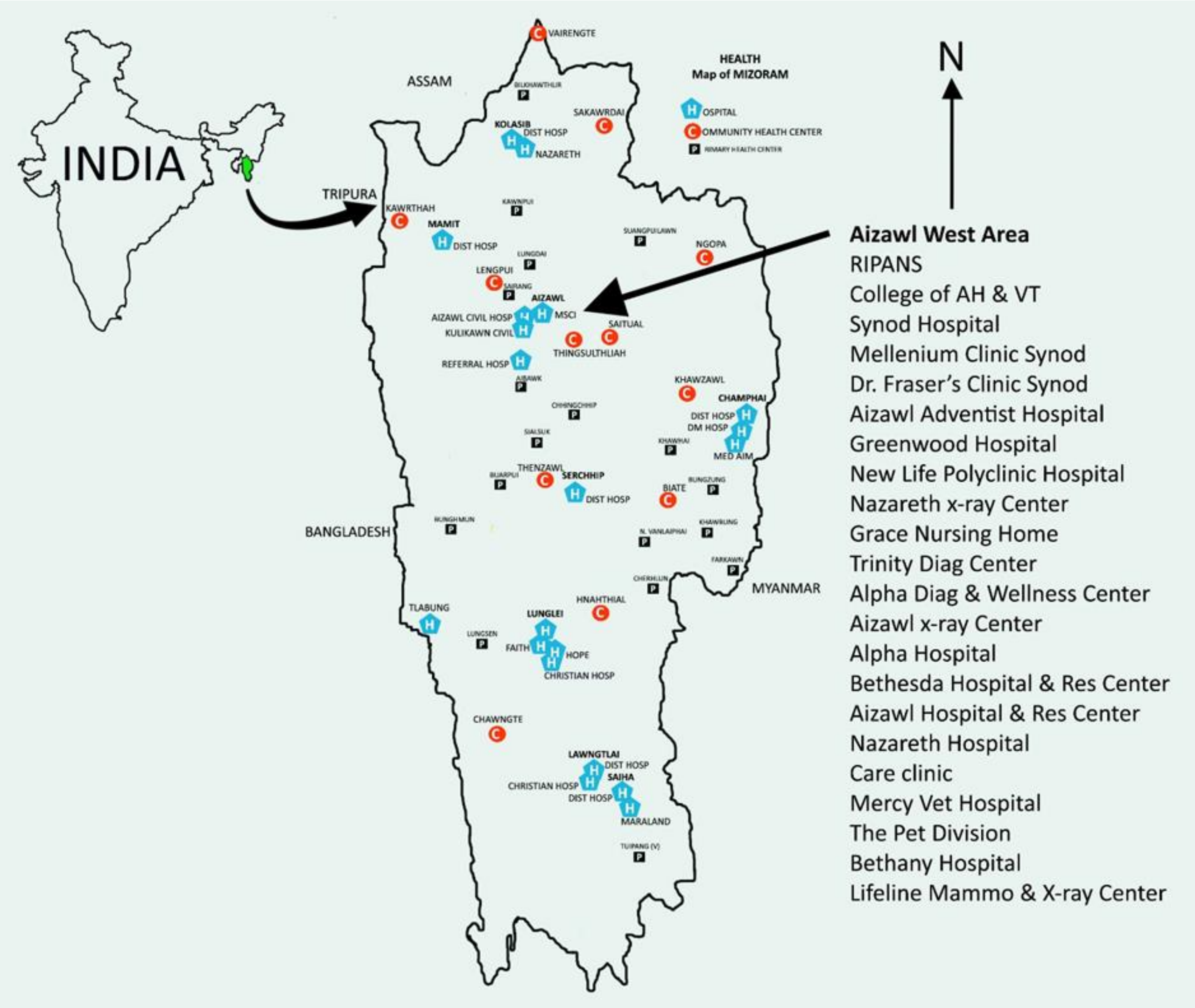

Figure 1 | Map showing various locations of institutions (93 machines were installed in 72 different institutions; 22 institutions in Aizawl west area were listed to the side).

Figure 2 | Pressurized ion chamber survey meter (model 451 P, Fluke Biomedical).

through a shield of any thickness without having an interaction.[7]

As early as 1899, WH Rollins, a dental physician in Boston, USA, introduced the X-ray tube housing by using lead material as well as primary beam collimation to enhance image quality and radiation protection.[8] In the early days of medical imaging, lead shielding around the X-ray tube was used but before shielding became mandatory, about three decades had passed.[9] In the present day, tube leakage radiation is not emitted through the X-ray tube portal even though it is created inside the X-ray tube. Rather, leakage radiation is transmitted through X-ray tube housing.[10] This is why diagnostic X-ray tube housing is lined with thin sheets of lead. This shielding is intended to protect both the patients and personnel from leakage radiation.[11] Proper shielding of any X-ray tube, using the standard methodology and leakage limit, is mandatory for the radiation protection of the radiation workers, patients and the public.[12]

Studies have been performed on tube housing leakage of conventional diagnostic X-ray equipment in different parts of the world. Sungita *et al.*[13] in 2006 performed measurement of tube housing leakage on 47 units in Tanzania, and reported 'Most of the X-ray machines tested for tube leakage gave results that were below 0.5 mSv h^{-1} at 1 m, which complied with safety requirements. In 2012, Hassan *et al.*[14] studied X-ray diagnostic machines used at different medical diagnostic centers in Egypt; they reported that the measured dose of tube housing leakage was in the range of background values 0.15 μSv h^{-1} at 1m. Tsalafoutas[12] performed a study in excessive tube housing leakage due to the methodology used by the manufacturer on two separate mobile X-ray equipment. Tsalafoutas reported that even at a distance of 3 m from the tube, the leakage radiation exceeded the maximum permissible dose rate of the equipment. For the second unit, the dose-meter reading at 1 m from the tube was 12.1 μGy; for 1 h with tube current 4 mA, a leakage of 3.5 mGy was derived. The author concluded that after changing the methodology used by the manufacturer, the leakage radiation had been reduced to about 1/8 of its previous value and thus following the existing leakage radiation limit.

To the best of the authors' knowledge, no tube housing leakage measurement has been done so far in the present study area. Keeping this in mind, this study was conducted to quantify leakage radiation with the international standard test procedure to all working conventional diagnostic X-ray machines in the present study area. Further, the results were compared to Atomic Energy Regulatory Board (AERB -India), National Council on Radiation Protection and Measurements (NCRP-USA), European Commission standard norms and including the previous study as well.

Materials and Methods

The total number of working and out of order diagnostic X-ray machines recorded in Mizoram was 169 in 116 different institutions until June 2016. However, in the present study, the authors considered 111 (65.68%) conventional diagnostic X-ray units. In view of the total workloads of all X-ray facilities, conventional X-ray contributed 90.94% and other 9.06% were shared between dental X-rays and other (CT-scan, fluoroscopic & mammographic) procedures; the detail was published in the previous study.[15-16] These workloads were calculated from several parameters such as; patients per day, films per patient, mAs per film and days per week by using formula given by NCRP.[16-17] The authors classified all the working conventional units into fixed, mobile-fixed and mobile unit. Out of all that, 93 (55.03%) working conventional diagnostic X-rays which were installed in 72 different hospitals were studied. The present study area and the location of different hospitals, community health centers and primary health centers were shown in **Figure 1**.[18]

For measuring leakage radiation, pressurized ion chamber survey meter (model 451 P, Fluke Biomedical, Everett, WA, USA) was used (**Figure 2**). The calibration measurements were traceable to the National Institute of Standards and Technology (NIST, Gaithersburg, MD, USA). The response time of the survey meter was 5 s for 0 μR h^{-1} to 500 μR h^{-1} (0 μSv h^{-1} to 5 μSv h^{-1}); 2 s for 0 mR h^{-1} to 5 mR h^{-1} (0 μSv h^{-1} to 50 μSv h^{-1}); 1.8 s for 0 mR h^{-1} to 500 mR h^{-1} (0 mSv h^{-1} to 5 mSv h^{-1}). The survey meter has accuracy of ± 10% reading between 10% and 100% of full-scale indication on any range with precision within 5% reading.[19] All the measurements were carried out in freeze mode.[20] To measure leakage radiation from X-ray tube, the collimator diaphragms were closed completely and the tube was projected vertically downward. So, the tube is oriented in such a way that the anode is over the head of the table and the cathode is over the foot. When facing the X-ray tube assembly, the anode is on the radiographer's left and the cathode is on the right. The tube leakage measurements were done at a 1 m focus-to-detector distance (FDD) by putting detector at five different positions *viz*. left, right, front, back and top of the X-ray tube. The exposure parameters for the present study were maximum accelerating potential (kVp), maximum tube current (mA) and fixed exposure time (sec).[9, 12-14, 21]

According to the AERB safety code 2001 for 'medical diagnostic X-ray equipment and installations' it is mentioned that 'every tube housing for medical diagnostic X-ray equipment shall be so constructed that the leakage radiation through the protective tube housing in any direction, averaged over an area not larger than 100 cm^2 with no linear dimension greater than 20 cm, shall not exceed an air kerma of 115 mR (1 mGy) in one hour at a

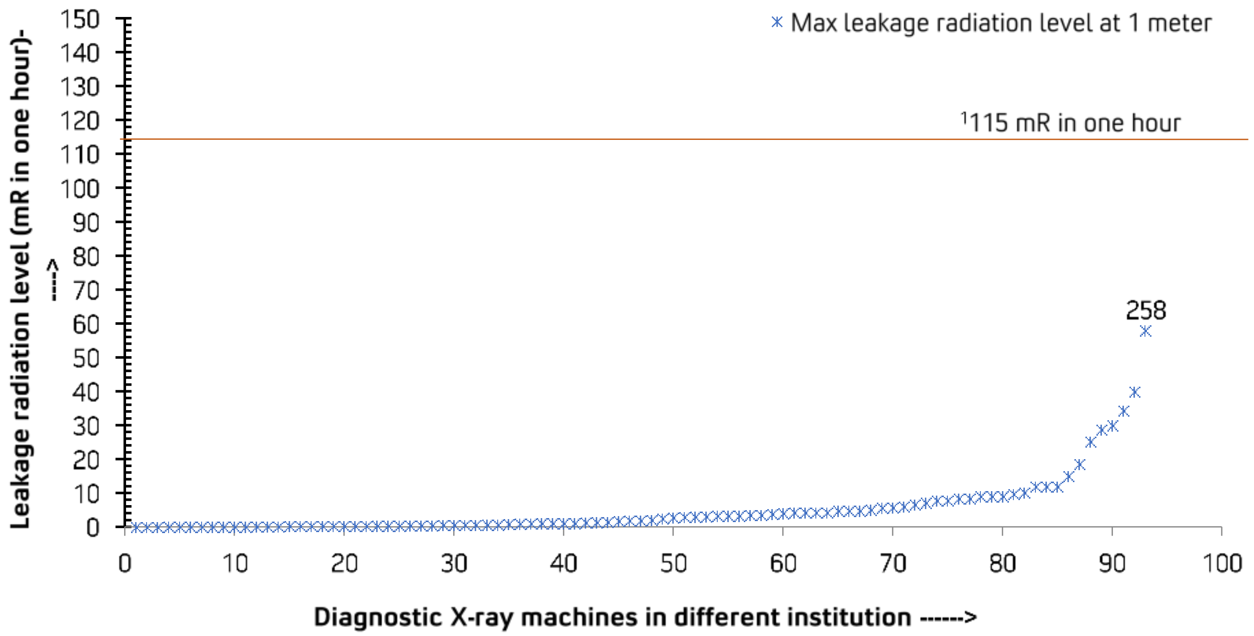

Figure 3 | Maximum tube housing leakage radiation in 93 X-ray machines [AERB[1] and other regulatory body safety limit 115 mR in one hour;[2] maximum leakage 58 mR in one hour].

distance of 1 m from the X-ray target when the tube is operating at the maximum rated kVp and for maximum rate current at that kVp'.[22] Again, it was reported that the leakage radiation from the tube housing measured at a distance of 1 m from the focus should not exceed 1 mGy (115 mR) in one hour.[23] In addition to that, in the NCRP report No. 147, it was given that the manufacturers were required by regulation to limit the leakage radiation to 0.876 mGy h^{-1} (100 mR h^{-1}) at 1 m.[17] Compliance with this requirement should be evaluated using the maximum X-ray tube potential and the maximum beam current at that potential for continuous tube operation. Furthermore, data presented as mean, range and standard error mean were analyzed by using SPSS statistics for windows version 17.0. (SPSS, Inc., Chicago, IL, USA). T-test was also conducted to check the the existence of significant difference between the amount of leakage radiation measured at different position with respect to the X-ray tube.

Results and Discussion

The tube housing leakage exposure rates measured for 93 diagnostic X-ray machines in each five different positions (i.e. left, right, front, back, and top) of the X-ray tube were shown in **Table 1**. Exposure rate 0.03 mR h^{-1} was the lowest leakage exposure measured and it was found in back and top positions of the X-ray tube. Leakage exposure rate, 500 mR h^{-1} was the highest leakage radiation rate from all 93 X-ray machines and it was measured in the front direction of the X-ray tube (**Table 1**). Comparing radiation exposure rates measured at different positions; rates measured at the front direction of the tube has the highest mean±SEM of 41.61±8.63 mR h^{-1} and rate measured at the top position of the tube has the lowest mean ± SEM of 4.57±1.16 mR h^{-1}. Therefore, it can be said that radiation leakage in the present study was high in the front position of the tube, whereas, it was low at the top position of the X-ray tube. In addition to that, t-test was performed between leakages exposure rates measured at these five different positions, and the results showed that there was a significant difference (0.01 level) between the top position and the other four directions of the X-ray tube. X-ray tube leakage at the top direction was significantly less than the other four directions. Tsalafoutas[12] reported that there was an excessive leakage radiation from each position except for one position on the top of the new mobile X-ray tube housing. So, similar case was found in the present study, when compared to the others, the top position showed relatively low leakage radiation rate (**Table 2**).

From each five different positions of measurement, the authors selected the highest leakage exposure rates from all the X-ray machines. Then, the maximum leakage radiation level at 1 meter from the tube (mR in one hour) of the X-ray equipment were calculated by using the given equation (Figure 3);[24]

$$\text{Max leakage} = \frac{180\ \text{mA.min in 1 hr} \times \text{Maximum Exposure level} \left(\frac{\text{mR}}{\text{hr}}\right)}{60 \times mAusedformeasurement}$$

Table 1 | Tube housing leakage exposure rates measured at left, right, front, back, and top direction of the X-ray tube.

Parameters	N	Minimum ($mR\ h^{-1}$)	Maximum ($mR\ h^{-1}$)	Range ($mR\ h^{-1}$)	Mean ($mR\ h^{-1}$)	Std. error of the mean ($mR\ h^{-1}$)
Left	93	0.09	400	399.91	33.51	6.65
Right	93	0.04	400	399.97	37.32	6.87
Front	93	0.04	500	499.96	41.61	8.63
Back	93	0.03	290	289.97	17.67	4.86
Top	93	0.03	70	69.97	4.57	1.16

Table 2 | Comparison of radiation leakage between left, right, front, back and top direction of X-ray tube.

Position of the survey meter w.r.t. X-ray tube	N	t-value	Significance Level
Left and top position	93	4.29	0.01
Right and top position	93	4.7	0.01
Front and top position	93	4.25	0.01
Back and top position	93	2.62	0.01

Table 3 | Comparison between maximum leakage radiation in AERB type and unknown type approval units.

	N	Mean	t-value	Significance Level
AERB Approved units	66	6.97	2.63	0.01
Not known approval units	27	1.52		

Table 4 | Comparison between maximum leakage radiation in fixed and mobile X-ray machines.

	N	Mean	t-value	Significance Level
Fixed X-ray machines	41	4.55	0.76	0.01
Mobile-fixed X-ray machines	52	6.04		

The calculated maximum tube housing leakage radiation from 93 X-ray machines ranged between 0.01 mR in one hour to 58 mR in one hour with 5.39±0.97 mR (mean±SEM) in one hour. Leakage radiation levels from 93 X-ray machines were compared to the national and international standard norms; it was found that all the machines complied with the safety standard.[22-23] The highest leakage radiation level was 50.43% of the standard limit. The present result is more or less similar to previous studies conducted by Sungita *et al.*[13], in Tanzania (2006) and Hassan *et al.*[14], in Egypt (2012). However, in the present study, leakage radiations appeared to be relatively higher than the previous studies.

According to AERB type approval machine, 66 machines were AERB type approved units where 27 machines were unknown approval due to lack of information as these machines were so old. The minimum leakage radiation level in AERB type approved units was 0.02 mR in one hour and the maximum was 58 mR in one hour having 6.97±1.31 mR (mean±SEM) in one hour. Further, minimum leakage radiation level in not known approval units was 0.01 mR in one hour and the maximum was 8.40 mR in hour with mean±SEM 1.51±0.46 mR in one hour. It appears that the leakage radiation level was higher in AERB type approved machines than the unknown approval type. The t-test also showed that the existence of significance difference (0.01 level) between AERB type approved unit and unknown approval status (**Table 3**). Besides, as already mentioned, both types of all the machines were within safety standard.

Regarding fixed and mobile X-ray machines, 52 machines were mobile X-rays, where, 41 were fixed X -ray equipment. Leakage radiation in fixed X-rays ranged between 0.02 mR in one hour to 58 mR in one hour with mean ± SEM 6.04±1.53 mR in one hour. In mobile X-rays, leakage radiation ranged from 0.01 mR in one hour to 30 mR in one hour with mean ± SEM 4.55±1.04 mR in one hour. It was found that the leakage radiation level was relatively higher in mobile X-ray than fixed X-ray machines even though fixed X-ray can operate at relatively high input parameters. However, there was no significant difference (0.01 level) between fixed and mobile X-ray machines (**Table 4**). Further, the correlation between the tube housing leakage and the age of the X-ray machine was only 0.15, therefore, the X-ray tube age is not one of the important reasons for the present tube housing leakage radiation.

Conclusion

In the present study it was found that the tube housing leakage radiation level among 5 different positions (i.e. left, right, front, back, top) was highest in the front direction of the tube and lowest at the top direction of the X-ray tube. In comparison to national and international safety standard, all the equipments were well below the safety limit. Regarding fixed and mobile X-ray machines, there was no significant difference in leakage radiation even though fixed X-ray can operate at higher input parameter.

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Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Supplementary Materials

Table A | Maximum leakage radiation from each piece of equipment.

Parameters	N	Minimum (mR in one hour)	Maximum (mR in one hour)	Range (mR in one hour)	Mean (mR in one hour)	Std. error of the mean (mR in one hour)
Maximum leakage	93	0.01	58	57.99	5.39	0.97

Table B | Maximum leakage radiation in AERB type approved machines and not known type approval.

Parameters	N	Minimum (mR in one hour)	Maximum (mR in one hour)	Range (mR in one hour)	Mean (mR in one hour)	Std. error of the mean (mR in one hour)
AERB type approved	66	0.02	58	57.98	6.97	1.31
Not known type approval	27	0.01	8.40	8.39	1.51	0.46

Table C | Maximum leakage radiation in mobile X-ray and fixed X-ray machines.

Parameters	N	Minimum (mR in one hour)	Maximum (mR in one hour)	Range (mR in one hour)	Mean (mR in one hour)	Std. error of the mean (mR in one hour)
Mobile X-ray	52	0.02	58	57.98	6.04	1.53
Fixed X-ray	41	0.01	30	29.99	4.55	1.04

Table D | Maximum leakage radiation level (mR in one hour) for 93 diagnostic X-ray machines.

X-ray units	Leakage Exposure Level (mR h^{-1})						Max radiation leakage (mR in one hour)
	Left	Right	Front	Back	Top	Max Exposure level (mR h^{-1})	
147	0.11	0.035	0.04	0.04	0.05	0.11	0.01
111	0.11	0.09	0.28	0.03	0.03	0.28	0.02
168	0.25	0.24	0.5	0.08	0.05	0.5	0.02
6	0.5	0.7	0.21	0.5	0.14	0.7	0.04
63	0.26	0.5	0.15	0.4	0.5	0.5	0.06
140	0.2	0.22	1.2	0.11	0.1	1.2	0.07
17	0.3	0.5	0.34	0.33	0.43	0.5	0.08
55	1	0.25	0.6	0.8	0.05	1	0.08
106	1	0.6	0.32	0.06	0.04	1	0.1
132	0.7	0.49	0.23	0.27	0.6	0.7	0.11
134	2.2	0.4	0.25	0.12	0.09	2.2	0.13
148	0.95	0.14	0.29	0.45	0.24	0.95	0.14
146	1.1	2.1	0.10	0.1	2.1	2.1	0.16
152	0.43	1.45	1.3	0.15	0.07	1.45	0.17
145	0.42	2	2	0.1	0.1	2	0.24
116	0.26	1.4	1.8	0.1	0.5	1.8	0.27
155	1.6	0.5	0.43	0.1	1.9	1.9	0.29
2	0.4	0.47	5	0.1	0.8	5	0.3
61	2	2	1.2	0.35	0.12	2	0.3
110	0.09	0.06	1	0.5	0.08	1	0.3
143	3.1	0.9	5	0.09	0.5	5	0.3

117	2.45	2.6	2.5	0.05	0.1	2.6	0.31
7	3	24	3.7	1.2	0.28	24	0.36
87	1.25	1.22	2.43	2.34	0.04	2.43	0.36
137	0.7	3.2	2.6	0.08	0.7	3.2	0.38
31	3.1	5	7	0.16	3.2	7	0.42
5	0.12	0.18	2.4	0.14	0.06	2.4	0.48
151	1.9	1.9	8.5	0.11	0.12	8.5	0.51
48	19	31	35	9	0.38	35	0.53
41	3.7	2.2	1.4	0.05	0.2	3.7	0.56
56	3.9	0.8	1	3	0.09	3.9	0.59
136	3.3	4.3	3.7	0.17	6	6	0.6
42	2.5	11	2.7	1.7	1	11	0.66
54	4.5	0.5	0.8	0.07	0.04	4.5	0.68
149	8.5	2	14.5	0.1	0.12	14.5	0.87
166	15	12	5	1	0.15	15	0.9
160	0.25	1.2	0.6	0.2	7	7	1.05
142	16	18	15	0.16	0.15	18	1.08
126	11	4.4	0.14	0.06	0.2	11	1.1
1	5	9.5	9.5	0.18	0.17	9.5	1.14
40	9.5	9.5	0.8	1.9	0.95	9.5	1.14
11	0.48	0.31	1	0.45	8.5	8.5	1.28
118	3	8	12	8	3	12	1.44
24	21	25	17	4.9	0.25	25	1.5
124	8	2.2	22	0.2	12	12	1.8
33	47	50	35	10	7	50	1.88
67	25	21	32	24	0.39	32	1.92
109	18	4.2	27	2.8	0.16	27	2.03
165	4.6	21	4.9	0.44	1.7	21	2.52
15	47	37	5	0.45	0.17	47	2.82
108	1.2	8.5	24	1.1	12	24	2.88
169	1.5	0.43	20	13	0.1	20	3
16	210	190	11	43	1.8	210	3.15
4	25	40	55	6	0.8	55	3.3
44	2.75	6	55	8	0.44	55	3.3
51	38	22	8	55	3.5	55	3.3
57	4.1	60	8	0.23	0.13	60	3.6
125	30	11	60	11	0.9	60	3.6
46	65	11	5.5	24.5	0.23	65	3.9
129	12	4.4	20	0.06	0.1	20	4
25	65	45	70	6	2.5	70	4.2
29	21.5	70	30	13	4.6	70	4.2
35	140	110	60	27	0.95	140	4.2
167	4.2	21	12	17	0.5	21	4.2
12	20.5	80	4.25	20.5	0.39	80	4.8
114	60	55	80	38	36	80	4.8
158	70	80	19	4.1	0.4	80	4.8
131	10	11	42	1	0.60	42	5.04
107	60	8	150	0.7	3	150	5.63
159	30	37	48	20	0.3	48	5.76
53	101	41	18	23	0.6	101	6.06
120	3.6	4.3	55	0.5	0.11	55	6.6
121	8.5	26	60	7.5	0.5	60	7.2
65	36	35	65	0.55	0.3	65	7.8
164	3.8	39	7	7.5	1.5	39	7.8
3	13	32	70	5	2.3	70	8.4

123	5.1	5.3	70	1.1	0.27	70	8.4
18	100	140	150	90	10	150	9
22	130	120	150	15	0.75	150	9
66	20	70	75	0.6	0.2	75	9
150	32.5	65	45	21.5	6	65	9.75
49	75	170	165	7	11	170	10
10	31	100	49	11	17	100	12
154	5.5	100	30	1.7	3.5	100	12
157	120	45	4.5	1.7	19	120	12
34	165	80	500	95	10.5	500	15
23	300	310	290	160	50	310	18.6
28	170	160	420	270	20	420	25.2
161	60	70	240	7.5	16	240	28.8
141	15	26.5	250	75	0.75	250	30
130	120	400	21	75	50	400	34.29
119	400	230	55	90	70	400	40
133	25	2.7	1.5	290	2.5	290	58

Table E | Details of the institutions/machines studied in the present study area.

No. of institutions	No. of machines	Name of institutions	Type	Model
		AIZAWL EAST		
1	1	Thingsulthliah CHC	MF	Intelix 100mA
2	2	Sakawrdai CHC	MF	ME 5085
3	3	Sub-District Hospital, Saitual	F	ME 1010
4	4	Suangpuilawn PHC	MF	ME 5085
		AIZAWL WEST		
5	5	Aibawk PHC	MF	ST 20 P
6	6	Sialsuk PHC	MF	ME 5085
7	7	State Referral Hospital, Falkawn	F	ME-3010
8	8	Lengpui PHC	MF	ST 20 P
9	9	Sairang PHC	MF	COMET-3
10	10	Mizoram State Cancer Institute	F	ME 5025
11	11	Civil Hospital, Room No 3	F	ME-3010
	12	Room No 4	F	ME-3010
	13	Room No 2	MF	Cosmos-5
	14	Ortho Department	MF	ME 5085
	15	X-ray Dept from Male &Paediatric	M	ME 5085
	16	Casualty	M	ME 5085
	17	Intensive Care Unit	M	ME 5085
	18	Morgue Room	MF	ME 5085
	19	Neonatal Intensive Care Unit	M	ME 5085
12	20	RIPANS	F	ME 5025
13	21	Kulikawn Civil Hospital	MF	ME 5085
14	22	College of AH & VT, Selesih	F	Heliophos-D
15	23	Synod Hospital	F	Pleophos-D
	24		F	Heliophos-D
16	25	Synod Hospital Millennium Clinic	MF	Multimobil 10
17	26	Dr. Fraser Clinic of Synod Hospital	MF	Genius 60
18	27	Aizawl Adventist Hospital	F	Olympicks 3012D
19	28	Greenwood Hospital, Bawngkawn	F	DIAGNOX-300
20	29	New Life Polyclinic Hospital, Chanmari	F	ME-3010
21	30	Nazareth X-ray Center (RIT), NIMAT	F	DXD-300
22	31	Grace Nursing Home, Lower Zarkawt	F	Allengers 325 FC

23	32	Trinity Diagnostic Center, Zarkawt	F	DX-525
24	33	Alpha Diagnostic & Wellness Center	F	DX-300
25	34	Aizawl X-ray Center, Dawrpui	F	DIAGNOX-60
26	35	Alpha Kulikawn	MF	Sappho Series
27	36	Bethesda Hospital & Research Center	MF	DIAGNOX-60
28	37	Aizawl Hospital & Research Center	F	DX-300
29	38	Nazareth Hospital, Ramhlun	MF	DIAGNOX-60
30	39	Care Clinic	F	AMS-100
31	40	Mercy Veterinary Hospital	MF	Allengers 100 CBM
32	41	The Pet Division	MF	MDX 100
33	42	Bethany Hospital	F	MDX 100
34	43	Lifeline Mammography& X-ray Center	F	Allengers 325
		LUNGLEI DISTRICT		
35	44	Christian Hospital, Serkawn	F	Siemens
	45		F	Heliophos D
36	46	Faith Hospital & Res Center, Lunglei	F	ME 1010
37	47	Hope Hospital, Lunglei	MF	Sappho 1010
38	48	Civil Hospital, Lunglei	MF	ME 5085
	49		MF	ME 5085
39	50	Lungsen PHC	M	ME 5085
40	51	Sub-District Hospital, Tlabung	MF	Comet 3
	52		MF	Intelix 100mA
41	53	Hnahthial CHC	F	ME 1010
	54		MF	Medico-P50
42	55	Cherhlun PHC	MF	Intelix 100mA
43	56	Buarpui PHC	F	ME 1010
44	57	Bunghmun PHC	M	Intelix 100mA
		SAIHA DISTRICT		
45	58	Tuipang PHC	MF	Comet 3
46	59	Maraland Gospel Centenary Hospital	F	DXD-3010 D
47	60	District Hospital, Saiha	F	3085-FR
		KOLASIB DISTRICT		
48	61	Nazareth Nursing Home, Kolasib	MF	AMS 60
49	62	Kawnpui PHC	MF	Medico-P50
50	63	Bilkhawthlir PHC	F	ME 1010
51	64	Vairengte CHC	MF	Comet 3
	65		MF	Stallion 20P
52	66	District Hospital, Kolasib	F	ME 3010
	67		F	Comet 8
53	68	Lungdai PHC	F	ME 1010
		MAMIT DISTRICT		
54	69	District Hospital, Mamit	MF	ME 5085
55	70	Kawrthah CHC	F	ME 1010
	71		M	ME 5085
		CHAMPHAI DISTRICT		
56	72	District Hospital, Champhai	MF	ME 5085
57	73	Bungzung PHC	MF	Intelix 100mA
57	74	DM Hospital, Champhai	F	Olympicks 100D
59	75	MED AIM Hospital, Zotlang	F	OMS 1010 D
60	76	Khawzawl CHC	MF	Comet 3
61	77	Khawhai PHC	MF	ME 5085
62	78	Biate CHC	MF	Stallion 20P
63	79	Khawbung PHC	MF	ME 5085
64	80	Farkawn PHC	MF	Intelix 100mA
65	81	Ngopa CHC	F	ME 1010

SERCHHIP DISTRICT				
66	82	Chhingchhip PHC	MF	Comet 3
67	83	N. Vanlaiphai PHC	MF	Medico-P50
68	84	District Hospital, Serchhip	F	ME 3010
	85		MF	MDX 100
69	86	Thenzawl CHC	MF	Comet 3
	87		F	ME 1010
LAWNGTLAI DISTRICT				
70	88	Chawngte CHC	MF	Stallion 20P
	89		F	ME 1010
71	90	District Hospital, Lawngtlai	F	ME 3010
	91		MF	Stallion 20P
72	92	Christian Hospital, Lawngtlai	F	ERGOPHOS
	93		MF	YAMATO

PHC = Primary Health Center; CHC = Community Health Center; F = fixed X-ray; MF = mobile fixed X-ray; M = mobile X-ray

Table F | Details of the institutions/machines which could not be studied in the present study area (due to out of order and collimator shutters not functioned).

No. of institutions	Name of Institutions	No. of machines	Type	Model
1	State Referral Hospital, Falkawn	1	MF	ME-5085
		2	M	Cosmos 5
2	State Vety Hospital	3	F	Unknown
3	Mizoram Health Care, Dawrpui	4	F	ME-3010
4	Ziki Diagnostic Center, Dawrpui	5	F	ME-3010
5	Vaivenga Hospital & Research Center	6	M	ME 5085
6	Civil Hospital, Lunglei	7	F	ME 3010
7	John williams Hospital	8	F	Multiphos 15 Single Tube
8	Chhipphir PHC	9	MF	ME 5085
9	Buarpui PHC	10	MF	ME 5085
10	District Hospital, Saiha	11	MF	ME 5085
11	W Phaileng PHC	12	MF	EP 331
12	District Hospital, Mamit	13	MF	Intelix 100mA
13	District Hospital,Champhai	14	F	ME 3010
14	Kawlkulh PHC	15	MF	Medico-P50
15	E Lungdar PHC	16	MF	Medico-P50
16	Barapansury PHC	17	F	Vision Medical Equip 100mA
		18	F	Allengers