X-Ray Backscatter Security Scanners at U.S. Airports

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Air-carrier crewmembers are occupationally exposed to higher doses of ionizing radiation than normally received by members of the general population. The Transportation Security Administration's (TSA's) new X-ray scanners have caused concern regarding the additional dose of ionizing radiation that persons would receive if scanned on a regular basis and the possible increased risk of skin cancer (1, 2).

The X-ray scanners used by the TSA are backscattering devices (Rapiscan Secure 1000, built by Rapiscan Systems). They use soft (low-energy) X-rays that bounce back from the body and nearby objects to form an image of the body and nearby objects. The manufacturer reports that the effective dose per scan is less than 0.0001 mSv and approximately 0.00003 mSv (a scan dose is the combined dose, front plus back) (3, 4). A Johns Hopkins University report indicates that the standard scan (3 seconds) using the manufacturer's recommended settings results in an effective dose of 0.0000146 mSv of 50 kVp X-rays (5).

Based on estimates by the International Commission on Radiological Protection (ICRP) for a working age (18-64) population, the lifetime increased risk of cancer is 12 in 100,000 per mSv and the lifetime increased risk of fatal cancer is 3.1 in 100,000 per mSv (6). The risks from the "manufacturer's worst case" scan dose of 0.0001 mSv are:

cancer
12 in 100,000 per mSv x 0.0001 mSv = 12 in 1,000,000,000;

fatal cancer
3.1 in 100,000 per mSv x 0.0001 mSv = 3.1 in 1,000,000,000.

In the U.S. in 1998, cancer caused approximately 24% of adult deaths (ages 20+) (7).

A position statement of the Health Physics Society (HPS) regarding use of ionizing radiation for security screening of individuals includes the following recommendations (8):
(1) a screening should not exceed an effective dose of 0.00025 mSv,
(2) an individual should not be exposed to more than an effective dose of 0.250 mSv in a year.

Assuming the "manufacturer's worst case" effective dose of 0.0001 mSv per scan, an individual scan dose is below the HPS recommended limit of 0.00025 mSv, and an individual could be scanned 2500 times and not exceed the HPS's recommended annual effective dose limit of 0.250 mSv.

The estimated average effective dose per year in 2006 to a member of the U.S. general population from non-medical sources was 3.20 mSv (9), i.e., equal to the dose from more than 32,000 "manufacturer's worst case" scans.

We estimate that the equivalent dose to the conceptus per scan is less than 58% of the effective dose to the mother per scan. The estimate is based on fluence-to-dose conversion coefficients calculated for anterior-posterior and posterior-anterior exposures to 50 keV X-rays for an adult and for a 3-month old conceptus (10, 11) and on the relative proportions of the total effective dose for a scan resulting from the anterior-posterior and posterior-anterior effective doses reported by Johns Hopkins University (5). The equivalent dose to the conceptus is less than 58% of the effective dose to the mother because the 50 kVp X-rays emitted by the scanners include X-rays at many energies, most of which are less energetic and less penetrating than 50 keV X-rays.

If one assumes that the entire dose used in calculating effective dose (E) was to the skin, and the "manufacturer's worst case" estimate of E = 0.0001 mSv per scan, then the worst case equivalent dose (H) to the skin is:

$$H = E / w_T = (0.0001 / 0.01) \text{ mSv per scan} = 0.01 \text{ mSv per scan}.$$

where $w_T = 0.01$, the tissue weighting factor for skin (6).

For a working age population, the ICRP estimates the risk of skin cancer is 670 in 10,000,000 per mSv and the risk of fatal skin cancer is 1.34 in 10,000,000 per mSv (6). Therefore, the risks from 1 scan (0.01 mSv) are:

skin cancer
670 in 10,000,000 per mSv x 0.01 mSv = 6.7 in 10,000,000;

fatal skin cancer
1.34 in 10,000,000 per mSv x 0.01 mSv = 1.34 in 1,000,000,000.

Thus, if the dose is entirely to the skin the estimated risk of cancer is 56 times the estimate based on effective dose (6.7 in 10,000,000 / 12 in 1,000,000,000 = 56), and the estimated risk of fatal cancer is 43% of that estimated from effective dose (1.34 in 1,000,000,000 / 3.1 in 1,000,000,000 = 0.43)

Federal Aviation Administration (FAA) occupational effective dose limits (12, 13) for non-pregnant crewmembers are 50 mSv in a year, with a 5-year average of 20 mSv per year. After a female crewmember declares her pregnancy to management, the equivalent dose to her conceptus is limited to 0.5 mSv in any month and 1 mSv for the remainder of her pregnancy. For skin, the FAA annual limit is an equivalent dose of 500 mSv to any 1 cm^2 area.

We examined 7863 nonstop flights by 3 U.S. carriers (6537 flights between city pairs within the 50 United States). To calculate annual route doses, etc., we made the following assumptions:

(1) Crewmembers worked 1000 block hours per year.
(2) On a route between city pairs, the return dose was the same as the outgoing dose.
(3) The level of solar activity was the mean for the period 1958-2003.
(4) There was no significant dose from solar particle events.
(5) There was no significant dose from radioactive cargo.
(6) There was no significant dose from rare sources such as radioactive clouds, terrestrial gamma ray flashes, and lightning strikes on the aircraft.
(7) The effective dose per scan was the "manufacturer's worst case" effective dose of 0.0001 mSv.
(8) The equivalent dose to the conceptus per scan was 0.000058 mSv (58% of the effective dose).

For each flight we calculated:

(1) route annual effective dose assuming no scans;
(2) route annual effective dose assuming 1 scan per flight;
(3) route annual equivalent dose to the conceptus with no scans;
(4) route annual equivalent dose to the conceptus with 1 scan per flight.

For routes with scans included we also calculated:

(1) percent of route annual effective dose resulting from scans;
(2) associated risks of cancer and fatal cancer:
    (a) assuming scan dose was an effective dose;
    (b) assuming scan dose was an equivalent dose to the skin and 100 times larger than the reported effective dose (see above).

We found:

(1) For a pregnant crewmember, the additional dose from the scans can reduce the number of flights she can fly before the equivalent dose to her conceptus reaches an FAA recommended limit.
(2) A scan resulting only in a skin dose would result in an increased risk of cancer but a decreased risk of fatal cancer. This is because the risk coefficient for skin cancer is high, but skin cancer is rarely fatal.
(3) For routes with the scan dose exceeding the flight dose (1% of routes), the total annual dose was less than 0.5 mSv.
(4) The scan dose was less than 10% of the total dose for 89% of the routes.

(5) The highest total dose route with scan was 6.6 mSv. For this route, the scan dose was less than 1% of the total dose.

Where the total dose was high, the scan dose was a small percentage of the total. On routes with small flight doses, the contribution of the scan dose to the total dose was quite high, but the total dose remained quite small.

Thus, the added occupational dose from being scanned by the TSA X-ray security scanner before each flight does not significantly impact radiation safety for most crewmembers. However, a pregnant crewmember should be aware that being scanned increases the dose to her conceptus and that these doses should not be neglected when planning future occupational doses to ensure that the dose to her conceptus does not exceed recommended limits.

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Notes and Tables

Table 1. Range of annual occupational doses to pilots with and without the scan dose included, based on 7863 flights within the 50 United States from 3 large US commercial air carriers.

7863 Flights	Dose rate (mSv per block hour)	Block hours per flight	Flights per 1000 block hours	Dose to pilot without scan (mSv)	Dose to pilot with scan (mSv)
Minimum dose rate flight*	0.0000218	0.456	2190	0.0218	0.241
Median dose rate flight**	0.00234	1.85	541	2.34	2.39
Average dose rate flight**	0.00227	2.07	483	2.27	2.32
Maximum dose rate flight***	0.00658	5.96	176	6.58	6.60

* This flight also had the minimum dose rate of any flight in the 6537 US-US flight database.
** Considering only the 6537 US-US flights.
*** This flight also had the maximum dose rate of any flight in the 6537 US-US flight database.

Table 2. Number of flights required for the dose to a pregnant crewmember's conceptus to exceed FAA recommended limits.

	Dose rate (mSv per block hour)	Block hours per flight	flights required to exceed monthly limit of 0.5 mSv with scan dose (and without)	flights required to exceed declared pregnancy limit of 1.0 mSv with scan dose (and without)
Minimum dose rate flight	0.0000218	0.456	7,360 (50,298)	14,719 (100,596)
Average dose rate US-US flight	0.00227	2.07	106 (107)	211 (213)
Maximum dose rate flight*	0.00658	5.96	13 (13)	26 (26)

* This flight also had the maximum dose rate of any flight in the database.

Table 3. Cancer risks for pilots calculated using worst case effective dose and worst case skin dose estimates, assuming 1 scan per flight, 1000 block hours flight time.

	Annual flight effective dose in mSv	Annual scan effective dose (equivalent dose to skin) in mSv	Risk of cancer from flight effective dose + scan effective dose (flight effective dose + scan equivalent dose to skin)	Risk of fatal cancer from flight effective dose + scan effective dose (flight effective dose + scan equivalent dose to skin)
Minimum dose rate flight	0.0218	0.219 (21.9)	2.89 in 100,000 (1.47 in 1,000)	7.46 in 1,000,000 (3.61 in 1,000,000)
Average dose rate US-US flight	2.27	0.048 (4.8)	2.78 in 10,000 (5.94 in 10,000)	7.19 in 100,000 (7.10 in 100,000)
Maximum dose rate flight*	6.58	0.0168 (1.68)	7.92 in 10,000 (9.02 in 10,000)	2.05 in 10,000 (2.04 in 10,000)

Estimate of Equivalent Dose to the Conceptus as a Percentage of the Effective Dose to the Mother

Given:
Effective dose from the front scan (Master unit) is 0.61 microrem (ref. 5)
Effective dose from the rear scan (Slave unit) is 0.85 microrem (ref. 5)
Total effective dose per scan is 0.61 + 0.85 = 1.46 microrem (ref. 5)
Front and rear scanners emit 50 kVp X-rays (ref. 5)

Assume front scan is equivalent to an anterior-posterior (AP) exposure
Assume rear scan is equivalent to a posterior-anterior (PA) exposure
Assume all 50 kVp X-rays are 50 keV X-rays (most will be lower energy, 50 keV is the maximum).

Fluence to effective dose conversion at 50 keV for AP is 3.68E-13 $Sv{\cdot}cm^2$ (ref. 11)
Fluence to effective dose conversion at 50 keV for PA is 2.35E-13 $Sv{\cdot}cm^2$ (ref. 11)
($Sv{\cdot}cm^2$ is the same as Sv / (particles / cm^2))

Prefixes:
micro = E-6 = x 10^{-6}
nano = n = E-9 = x 10^{-9}
pico = p = E-12 = x 10^{-12}

Unit conversions:
100 rem = 1 Sv
0.01 Sv = 1 rem

Find AP fluence:

fluence x coefficient = dose
therefore,
fluence = dose / coefficient
= 0.61 microrem / (3.68E-13 Sv / (particles / cm^2))
= (0.61 x 10^{-6} rem x (0.01 Sv / rem)) / (3.68E-13 Sv / (particles / cm^2))
= 0.61 x 10^{-8} Sv / (3.68 x 10^{-13} Sv / (particles / cm^2))

AP fluence = 16,576 particles / cm^2

Find PA fluence:

fluence x coefficient = dose
therefore,
fluence = dose / coefficient
= 0.85 microrem / (2.35E-13 Sv / (particles / cm^2))
= (0.85 x10^{-6} rem x (0.01 Sv / rem)) / (2.35E-13 Sv / (particles / cm^2))
= 0.85 x10^{-8} Sv / (2.35E-13 Sv / (particles / cm^2))

PA fluence = 36,170 particles / cm^2

For a 3-month old conceptus the fluence-to-absorbed dose coefficients are:

AP: 0.215 $pGy{\cdot}cm^2$ (ref. 10),
PA: 0.136 $pGy{\cdot}cm^2$ (ref. 10),

where $pGy{\cdot}cm^2$ is the same as pGy/(particle/cm^2).

Find AP dose to conceptus:

dose = fluence x coefficient

AP dose = 16,576 (particles / cm^2) x 0.215 (pGy / (particle / cm^2)) = 3,563.84 pGy

Find PA dose to conceptus:

dose = fluence x coefficient

PA dose = 36,170 (particles / cm^2) x 0.136 (pGy / (particle / cm^2)) = 4,919.12 pGy

Total dose to conceptus = AP dose + PA dose
= 3,563.84 pGy + 4,919.12 pGy
= 8,482.96 pGy
= 8,482.96 pGy x (1 nGy / 1000 pGy)
= 8.48296 nGy

Since the radiation is photons the radiation weighting factor is 1 and the equivalent dose is numerically the same as the absorbed dose, thus

Equivalent dose to the conceptus is 8.48296 nSv

Effective dose to the mother = 1.46 microrem x (0.01 Sv / rem)
= 0.0146 microSv x (1000 nSv / microSv)
= 14.6 nSv

So, as a percent of the effective dose to the mother, the equivalent dose to the conceptus is:

P = (equivalent dose to conceptus / effective dose to mother) x 100%

P = (8.48296 / 14.6) x 100%

P = (0.581) x 100%

P = 58.1%