A Survey of the Transport of Radioactive Materials by Air to, from and within the UK

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1. INTRODUCTION

Radioactive materials are frequently transported overseas by air for medical and industrial purposes. Among the advantages of this mode of transport is that urgent delivery is often required because some radionuclides are short lived. There are also a limited number of shipments by air within the UK. Scheduled passenger services or freight-only aircraft may be used. Packages of radioactive materials are transported in aircraft holds at recommended segregation distances from areas occupied by passengers and crew. Many workers are involved in air transport and it is necessary to have procedures in place to minimise their exposure to ionising radiation.

The IAEA Transport Regulations [1] form the basis for instructions governing the transport of radioactive materials issued by the International Civil Aviation Organisation (ICAO) – "Technical Instructions for the Safe Transport of Dangerous Goods by Air" [2]. Regulations for the transport of radioactive materials by air in the UK are made by the Department for Transport (DfT) and enforced by the Civil Aviation Authority (CAA). Paragraph 304 of the IAEA Transport Regulations [1] requires that “The relevant competent authority shall arrange for periodic assessments of the radiation doses to persons due to the transport of radioactive material, to ensure that the system of protection and safety complies with the Basic Safety Standards [3]”. As a result of this the DfT arranges for surveys to be carried out on the transport of radioactive materials by each mode of transport – air, sea, road and rail. The National Radiological Protection Board (NRPB) has carried out a series of these surveys over the past 20 years, as shown in Table 1, the most recent of which concerned the transport of radioactive materials by air [4], which is the subject of this paper. The IAEA Transport Safety Appraisal Service (TranSAS) highlighted the commissioning of these reports as an area of good practice [5]. Such studies can serve as a model for other competent authorities in the radioactive material transport sector.

Table 1 NRPB surveys into the transport of radioactive materials

Report number	Year	Title
NRPB-R115	1984	Radiation Exposure Resulting from the Normal Transport of Radioactive Materials within the United Kingdom
Contract report	1988	Radiological Impact of the Normal Transport of Radioactive Material by Sea
NRPB-M219	1990	Radiological Impact of the Normal Transport of Radioactive Materials by Air
NRPB-R255	1992	Radiation Exposure from the Normal Transport of Radioactive Materials within the United Kingdom –1991 Review
NRPB-M749	1996	Radiological Impact of the Normal Transport of Radioactive Material by Sea
NRPB-W39	2003	Survey into the Radiological Impact of the Normal Transport of Radioactive Material by Air

Occupational exposure of aircraft crew derives from a combination of cosmic ray exposure and additional exposure from the transport of radioactive materials. The surveys undertaken by NRPB are concerned with exposure from packages of radioactive material during transport by air.

2. RADIOLOGICAL IMPACT OF THE NORMAL TRANSPORT OF RADIOACTIVE MATERIALS BY AIR – 1990 STUDY

At the time of the 1990 study [6] packages containing radioactive materials were generally transported on passenger aircraft. International couriers, travelling frequently by air, were identified as the critical group of passengers with annual individual doses of about 0.4 mSv, excluding exposure to cosmic radiation. A similar maximum dose was estimated for crew. The study dealt with all aspects of transport to, from and within the UK, except helicopter transport of radioactive materials to oil and gas drilling rigs and production platforms around the UK. It was found that at peak periods there were up to 30 flights a day out of London Heathrow airport carrying radioactive materials, and around 4 flights per week carrying radioactive materials into London Heathrow airport. Table 2 summarises the numbers of packages of radioactive material carried to and from the UK via London Heathrow airport, together with the mean and total Transport Index (TI) [7].

Table 2 Packages of radioactive material carried to and from the UK, 1990 study

Carrier	Flights per year	Mean TI	Total Annual TI	Packages per flight	Packages per year
UK exports					
A UK major airline	3000	4	12000	15	45000
40 other airlines	4000	2.5	10000	15	60000
A freight airline	200	65	13000	225	45000
UK imports					
Non-UK airline	200	12.5	2500	20	4000

Table 3 shows the doses to passengers and crew from the air transport of radioactive material, as estimated in the 1990 survey.

Table 3 Doses to passengers and crew from air transport of radioactive material, 1990 study

Air crew and passengers	Annual individual dose (µSv)	
	Average	Maximum
Flight deck crew	<0. 1	<40
Cabin crew, short-haul	3.6	360
Cabin crew, long-haul	0.4	40
Passengers, <10 flights per year	<0.1	30
Passengers, 40 flights per year	<0.1	100
Couriers, daily flights	17.0	420

3. SURVEY INTO THE RADIOLOGICAL IMPACT OF THE NORMAL TRANSPORT OF RADIOACTIVE MATERIAL BY AIR - 2003 STUDY

The scope of this study [4] was to

- Determine transport and working patterns as well as taking measurements onboard aircraft transporting radioactive materials.
- Identify significant operations in terms of numbers of packages and/or people involved, as well as any operations that could give rise to significant exposures.
- Cover all types of airports and categories of aircraft, including scheduled passenger, cargo only and dedicated charter flights.
- Assess maximum and collective doses to workers (including ground crews) and members of the public.
- Make comparisons with the previous survey [6] to identify trends.

This was achieved through a combination of postal questionnaires and visits to carrier sites. A preliminary letter to operators identified those that transported radioactive materials, and which locations were used. This information, together with other data from literature reviews facilitated the development of a questionnaire and the planning of a programme of visits to carrier sites.

4. CURRENT OPERATIONS IN THE UK

A major producer in the UK of industrial and medical radionuclides has a major world-wide export market. These radionuclides are often short-lived, so require urgent delivery by air. Molybdenum used for the production of technetium generators is imported to the UK from Africa about three times per week. Around half of the Type A packages exported from the UK are technetium generators, with Type A packages outnumbering Excepted packages by about 2 to 1.

Transport operations have changed since the previous study [6]. The major UK air carrier of radioactive materials identified in the previous study as carrying 30% of export packages no longer carries radioactive materials on its aircraft. Several major cargo carriers now ship from a number of airports around London and Birmingham, whereas at the time of the previous survey it was understood that 90% of radioactive materials for export were shipped through London Heathrow airport. Passenger aircraft are now used much less frequently for the transport of radioactive materials.

To obtain information from the carriers, a questionnaire was developed asking for information about the number of packages containing radioactive material carried on flights into, from and within the UK, as well as those that were in transit in the UK. The questionnaire also asked for the number of flights into, from and within the UK, or in transit, carrying radioactive materials, and also the number of flights not carrying radioactive material. The questionnaire also asked for information on the total TI carried on all flights; the numbers of aircraft crew; the number of flights per member of aircraft crew and the numbers of aircraft crew per flight; the numbers of passengers; and the maximum number of flights taken by any frequent flying passenger (e.g. courier). All of this information was requested for the year 2001 and for different types of flights e.g. short haul and long haul, passenger flights and cargo only flights. This was sent out to the air carriers identified as carrying radioactive materials by the response to the preliminary letter.

Of about 300 companies that were sent the preliminary letter, 88 responses were received. Around half of these indicated that they no longer carry radioactive materials, and the main questionnaire was sent to 49 operators, of which 27 responded, completing the questionnaire at least partly. Many companies found it difficult to provide data on some or all of the questions, as the information is not kept, or was not readily available. Therefore the data in Tables 4 to 6 were not necessarily supplied by the same groups of operators, and comparisons between the data from one table to another could be misleading. Table 4 shows the summary of responses, from 27 operators, on the numbers of packages carried in 2001. The information supplied shows that some 74,000 packages were carried, and over 80% of these were exports from the UK.

Table 4 Packages of radioactive material carried by air in 2001

	Short haul				**Long haul**		**Total**
	Passenger		**Cargo**		**Passenger**	**Cargo**	
	unit*	**loose‡**	**unit***	**loose‡**	**unit***	**unit***	
Into the UK	245	981	4111	4	2920	1383	9644
From the UK	2533	3104	14540	2746	13197	26015	62135
Within the UK	0	379	0	39	N/A	N/A	418
In transit	0	310	600	595	23	23	1551

* Wide body aircraft loaded with unit load devices (ULDs) to carry cargo
‡ Narrow body aircraft unable to take ULDs, cargo is loaded loose into aircraft

The data given in Table 5 were from 26 operators and gives information on the total number of flights, and the number carrying radioactive cargo. From these data it is possible to derive the radioactive traffic factor (RTF) for each type of flight, together with an overall RTF. The RTF is the ratio of the number of flights carrying radioactive materials to the total number of flights. Although the definition applies to the transport of Category II and III Yellow packages, it is assumed that at least one of these is carried in each consignment. An overall RTF for all flights provided is approximately 1 in 250. For short haul flights in passenger aircraft the RTF is approximately 1 in 500 and long haul passenger flights have an RTF of approximately 1 in 60. More packages are transported in cargo aircraft which results in a higher RTF than for passenger air craft: for short haul flights this value is 1 in 200; and just over 1 in 4 for long haul cargo flights. These values can be used in assessments to determine projected doses for aircrew and frequent fliers. The flight details provided for this study only represent part of the total number of flights into and out of the UK, as many operators do not carry radioactive material. Therefore, the RTFs calculated from the data in Table 5 are conservative values.

Table 5 Number of flights in 2001

	Short Haul				Long Haul		Totals
	Passenger		Cargo		Passenger	Cargo	
	unit*	loose‡	unit*	loose‡	unit*	unit*	
Into the UK	83393	28183	5762	1671	49496	2206	$1.7\ 10^5$
Into the UK carrying RAM	110	158	85	2	446	522	$1.3\ 10^3$
From the UK	823650	28257	5506	1651	50488	2147	$9.1\ 10^5$
From the UK carrying RAM	264	1112	419	103	1271	520	$3.7\ 10^3$
Within the UK	59143	104640	1040	104056	N/A	N/A	$2.7\ 10^5$
Within the UK carrying RAM	0	507	0	39	N/A	N/A	$5.5\ 10^2$
Total number of flights	966186	161080	12308	107378	99984	4353	$1.4\ 10^6$
Total number of flights carrying RAM	374	1777	504	144	1717	1042	$5.6\ 10^3$
Radioactive Traffic Factor (RTF) (rounded)	1 in 500		1 in 200		1 in 60	1 in 4	1 in 250
* Wide body aircraft loaded with unit load devices (ULD) to carry cargo ‡ Narrow body aircraft unable to take ULDs, cargo is loaded loose into aircraft							

Data on crew workload were obtained from 20 operators, for passenger and cargo aircraft. These data are summarised in Table 6, and show that the maximum number of flights on short haul aircraft is about 200, and 120 on long haul flights. The average number of passengers on short and long haul flights is, respectively, 76 and 247.

Table 6 Number of flights per crew member and numbers of crew per flight

	Short haul		Long haul	
	Passenger	Cargo	Passenger	Cargo
Average number of cabin crew per flight	5.5	n/a	12.4	n/a
Maximum annual number of flights per cabin crew member	200	200*	120	n/a
Average number of flight deck crew per flight	2	2.6	2.6	3
Maximum annual number of flights per flight deck crew member	128	192	108	36

* These are load operators that are required on some flights.

5. VISITS TO AIR CARRIERS

As well as collecting data through the postal survey, NRPB had meetings with the principal consignor of radioactive materials in the UK and with the major air carriers of packages of radioactive materials. Radiation measurements were made at airports and onboard both passenger and cargo aircraft. Three cargo carriers' and one passenger carrier's premises were visited. During these visits, a study was made of the operations involved, dose rates were measured in the cargo handling areas and on the aircraft, and cargo handlers' doses were assessed using integrating dosemeters.

At the three cargo carriers visited, the operations involving packages of radioactive materials were similar. Packages containing radioactive materials arrive at the airports by road in light trucks; the packages are then offloaded and checked in the carrier's warehouses. Each package is then sorted by destination and groups of packages are wrapped in cling film for transfer to Unit Load Devices (ULDs) for loading into the holds of the relevant aircraft. The ULDs containing packages of radioactive materials are usually loaded into the rear section of the cargo aircraft. At each site a team of workers was involved with handling the packages in the warehouse, and another team moves the ULDs onto the aircraft. Table 7 gives details of the packages seen at one of the warehouses, considered to be representative of the three sites visited. The packages were grouped ready for delivery to three destinations, and carried in a number of ULDs. The technetium generators (each typically containing 60 to 120 GBq of ^{99}Mo) contributed the most to the total TI for each group of packages, with each generator typically having a TI of between 2 and 3. Other packages included radionuclides typically for medical use, such as ^{51}Cr, ^{131}I and ^{33}P. A few packages containing non-radioactive "dry ice" material were being shipped with these packages.

Table 7 Technetium generators in warehouse

Destination	Total packages	Number of technetium generators	Total Transport Index
Destination 1	34	5	12.5
Destination 2	57	7	13.6
Destination 3	73	9	29.3

On the day of the visit to a passenger flight carrying radioactive material around 20 packages were present in the warehouse, and contained ^{99}Mo (technetium generators), ^{131}I and ^{201}Tl. These packages had a total TI of about 30. Packages were checked against documentation before being manually loaded into a ULD ready for transfer to the aircraft, the checker spending some 10 minutes in the vicinity of the packages. The dose rates close to the packages were around 40 μSv h^{-1}, and up to 800 μSv h^{-1} at the surface of the technetium generators. Some packages were destined for a later flight, and so after being checked, these packages were initially taken to a store area for radioactive materials prior to being loaded into a ULD. Dose rates around the first loaded ULD, including four technetium generators, are shown in Table 8.

Table 8 Dose rates at exterior surfaces of a ULD

Position	Dose Rate (μSv h^{-1})
Front (open, floor level)	600
Side (right side, centre)	40
Side (left side, centre)	35
Side (left side, floor level)	90
Back (centre)	80
Top	40

A small team of cargo handlers loaded the ULDs into the aircraft hold, most operations being made with mechanical lifting equipment. Handlers worked close to the sides of the ULDs for around 2 minutes, at positions where dose rates were up to 50 μSv h^{-1}. The ULDs were positioned in the hold with about 4 cm clearance to the roof of the hold; some 7 cm of aluminium cladding separated the roof of the hold from the cabin floor. Dose rates were measured on board the aircraft once loading was complete. The measured dose rates in the warehouses and on the aircraft were used to estimate doses to warehouse workers, crew and passengers.

6. DOSES TO WAREHOUSE WORKERS

Packages containing radioactive materials that are transported by air all pass through cargo warehouses. Dedicated teams of around 4 to 8 workers handle the dangerous goods packages. Workers who regularly have contact with packages containing radioactive materials, and some other workers close to these operations, have their doses regularly monitored. Typically about 20 workers wear personal dosimeters at each warehouse site. Dose reports for warehouse handlers show that monthly doses are generally less than 0.1 mSv, although a few workers tend to receive about 0.2 mSv monthly. The maximum annual dose received by a package handler is unlikely to exceed about 2 mSv. At one site visited, integrating dosemeters were supplied to the two main handlers of packages of radioactive material, and their total handling times were recorded. The dosemeters were worn for four days in a typical week and the results are shown in Table 9. These doses imply that monthly doses of around 0.2 to 0.3 mSv are likely – which corresponds to the doses recorded by their personal dosimeters. Also, the implied average dose rates were similar to those measured during the visits.

Table 9 Daily variation of worker dose and TI at one air carrier site

Day	Worker 1			Worker 2			TI handled
	Dose, μSv	Exposure time, min	Average dose rate during handling, $\mu Sv\ h^{-1}$	Dose, μSv	Exposure time, min	Average dose rate during handling, $\mu Sv\ h^{-1}$	
Monday	-	-	-	0	35	0	0.8
Tuesday	15	50	18	11	50	13	24.8
Wednesday	8	35	14	13	35	22	19.4
Thursday	4	35	7	3	35	5	7.7
Friday	17	30	34	51	45	68	61.5

Loading workers in the hold of the aircraft are in areas with lower average dose rates, although they will be present for longer, as the aircraft is also loaded with non-radioactive cargo. However, with the lower dose rates, and as these workers tend to work in rotation, it was estimated that their annual doses would be much less than 1 mSv. Therefore loaders on the aircraft do not generally wear personal monitors.

Measurements were made on board three cargo-only aircraft and one passenger aircraft. Dose rates in the flight crew areas were all at background levels. On the passenger plane, the highest dose rate measured in a cabin crew seat was 4 $\mu Sv\ h^{-1}$, but as cabin crew are generally only in their seats for take-off and landing their dose for the entire flight would be less than the dose predicted by this dose rate. On this passenger aircraft, the dose rates measured in the pilot and co-pilot's seats were at or below 0.5 $\mu Sv\ h^{-1}$. Measurements were made on the day that the aircraft was carrying the highest TI, of approximately 20. These crew seat dose rates were on a short haul flight, but are here also taken as representative of long haul flights. The measured dose rate found on the passenger aircraft was also assumed to apply to cargo aircraft.

Information on duty hours and flight times, together with the radioactive traffic factor determined for each flight type, was used with the measured dose rates to provide the estimates of average annual dose shown in Table 10. The assumed dose rates indicated in the table are likely to give upper estimates of the average annual dose to crew. The highest average annual dose was estimated as approximately 60 μSv for long haul cabin crew on passenger aircraft. A maximum annual dose to these crew was estimated to be about 200 μSv, assuming 50% of their flights carry radioactive material, but taking into account the variation in TI carried throughout a typical week, and the fact that these crew move around the cabin during a flight.

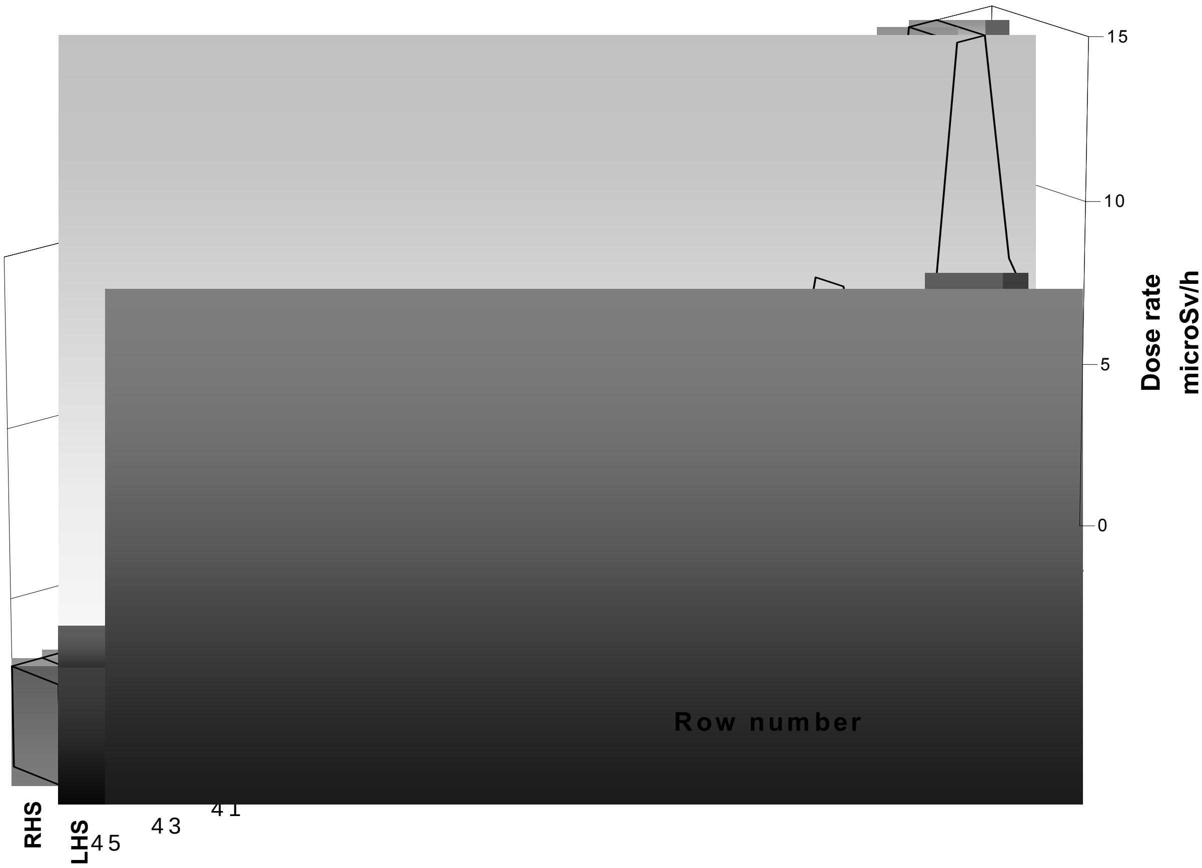
Table 10 Average annual air crew doses from radioactive cargo

Route	Cabin crew		Flight crew	
	Assumed dose rate, $\mu Sv\ h^{-1}$	Average annual dose, μSv	Assumed dose rate, $\mu Sv\ h^{-1}$	Average annual dose, μSv
Short haul - passenger	4	3.4	0.5	0.3
Short haul - cargo	-	-	0.5	1.2
Long haul – passenger	4	64	0.5	7.2
Long haul - cargo	-	-	0.5	36

7. DOSES TO PASSENGERS

On the passenger aircraft visited, ULDs containing radioactive material were loaded onto the aircraft, placed towards the front of the aircraft and towards the rear. Dose rate measurements were made on board the aircraft before the passengers boarded. Figure 1 shows the dose rates measured at points along the left and right hand aisles of the aircraft. The majority of passengers were not seated above the packages of radioactive materials in the hold. The average dose rate onboard the aircraft was 3 $\mu Sv\ h^{-1}$, with around half the passengers exposed to dose rates below 1 $\mu Sv\ h^{-1}$. The maximum dose rate was 15 $\mu Sv\ h^{-1}$. Therefore, with a flight time of 1.5 hours, passenger doses could be up to 20 μSv for the entire flight, the average dose being 4.5 μSv.

Figure 1 Dose rate measurements onboard an Airbus A300-600



With only 1 short haul flight in 500 carrying radioactive material, the average annual individual dose would be low. Even a frequent flier would be unlikely to always travel in conjunction with radioactive material and also be seated above the radioactive packages on numerous occasions. The most conservative assumption that a frequent flier flies in conjunction with radioactive material once per week would result in a potential annual dose of around 200 μSv. In reality a frequent flier is unlikely to receive any significant dose from cargo, due to the low frequency of passenger flights carrying radioactive materials, and the low dose rates found on board the aircraft.

8. CONCLUSIONS

A study has been carried out that gives information on contemporary practices in the transport of radioactive material by air. One specific trend that has been established is that cargo aircraft carry a much greater proportion of the total traffic of packages than at the time of the previous survey. In the 1990 study [6] the RTF was taken to be 1 in 10. In the current study a range of RTFs were derived for different types of flights, ranging from 1 in 4 for long haul cargo flights to 1 in 500 for short haul passenger flights.

Overall, the study found that the annual radiation dose to workers from these consignments is low. The maximum annual dose to air crew is estimated to be no more than 0.2 mSv. Radioactive materials carried on passenger aircraft would typically result in an average dose to passengers of a few microsieverts during a flight, and because of the low RTF, this would represent an annual dose in the order of one microsievert. Frequent fliers, using very conservative assumptions, are unlikely to receive more than 0.2 mSv annually. Workers who handle these packages in airport warehouses are unlikely to receive more than 2 mSv annually.

In the previous and recent studies, average and maximum annual individual doses to cabin crew and flight deck crew were found to be well below 1 mSv. In the previous study, short-haul cabin crew were identified as having the highest average and maximum annual individual exposure. In the current study it is the long-haul cabin crew. However, the previous and recent estimates of annual doses are similar within about a factor of two.

The critical group of passengers was previously identified as international couriers with annual doses up to about 0.4 mSv from the packages in the holds. Such couriers have not been identified in the current study. This difference may be a reflection of the diminished importance of shipment by passenger aircraft.

9. REFERENCES AND NOTES

1. IAEA. Regulations for the Safe Transport of Radioactive Materials, 1996 Edition (Revised), No. TS-R-1, IAEA, Vienna (2000).

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4. Warner Jones S.M., Shaw K.B. and Hughes J.S. Survey into the Radiological Impact of the Normal Transport of Radioactive Material by Air. NRPB-W39 (2003).

5. IAEA. Appraisal for the United Kingdom of the Safety of the Transport of Radioactive Material. TranSAS-3, IAEA, Vienna (2002).

6. Gelder R. Radiological impact of the Normal Transport of Radioactive Materials by Air. NRPB-M219 (1990).

7. The Transport Index (TI) of a package is a number that is used to provide control over radiation exposure, and is defined in the IAEA Transport Regulations [1]. For the packages in this study it is the number obtained by taking the maximum dose rate in mSv h^{-1} at a distance of 1 m from the surface of a package and multiplying this value by 100.