AIRCREW: A UNIQUE OPPORTUNITY FOR NEUTRON HEALTH EFFECTS STUDIES

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- In 1965, the older T57D estimates of dose to survivors from the bombings in Japan was replaced with updated values provided by T65D, based on experiments in Nevada and data from other weapons tests.
- Hiroshima was thought to have significant neutron exposure due to the "gun" design of Little Boy, while Nagasaki did not due to the implosion which placed significant hydrogen in explosives symmetrically around the device.
- This usefully provided an estimate for the neutron quality factor which was based on human data for more than a decade.
- In 1978, H. Rossi and C. Mays published an analysis of survivor leukemia which showed that, based on T65D the quality factor for neutrons should be 100, rather than the 10 then in use.
- This would have severely impacted nuclear weapons production, operation of the Alternating Gradient Synchrotron, and greatly increased the complexity of neutron dosimetry for workers with less or trivial exposure.

TENTATIVE 1965 DOSIMETRY (T65D)

T65D ERRORS

- T65D, based in part on tests at the Nevada Test Site, failed to account for pressure and humidity differences between NTS and high humidity present in coastal cities in Japan
- As a result of Rossi and Mays paper, efforts were made to improve estimates of neutron leakage from the two different weapons, and also correctly account for sea level pressure and humidity.
- When T65D was corrected, the neutron dose for survivors in Hiroshima was 4 to 8 times lower at 1,000 and 2,000 meters, while the gamma dose was 1.2 to 1.3 times higher.
- This essentially eliminated the basis for the Rossi and Mays paper, and eliminated the human experimental basis for quality factor.
- Currently, quality factor is based on biological systems, such as mice, which have short life spans compared to humans

WGBH 2017 SPECIAL: "CITY IN THE SKY"

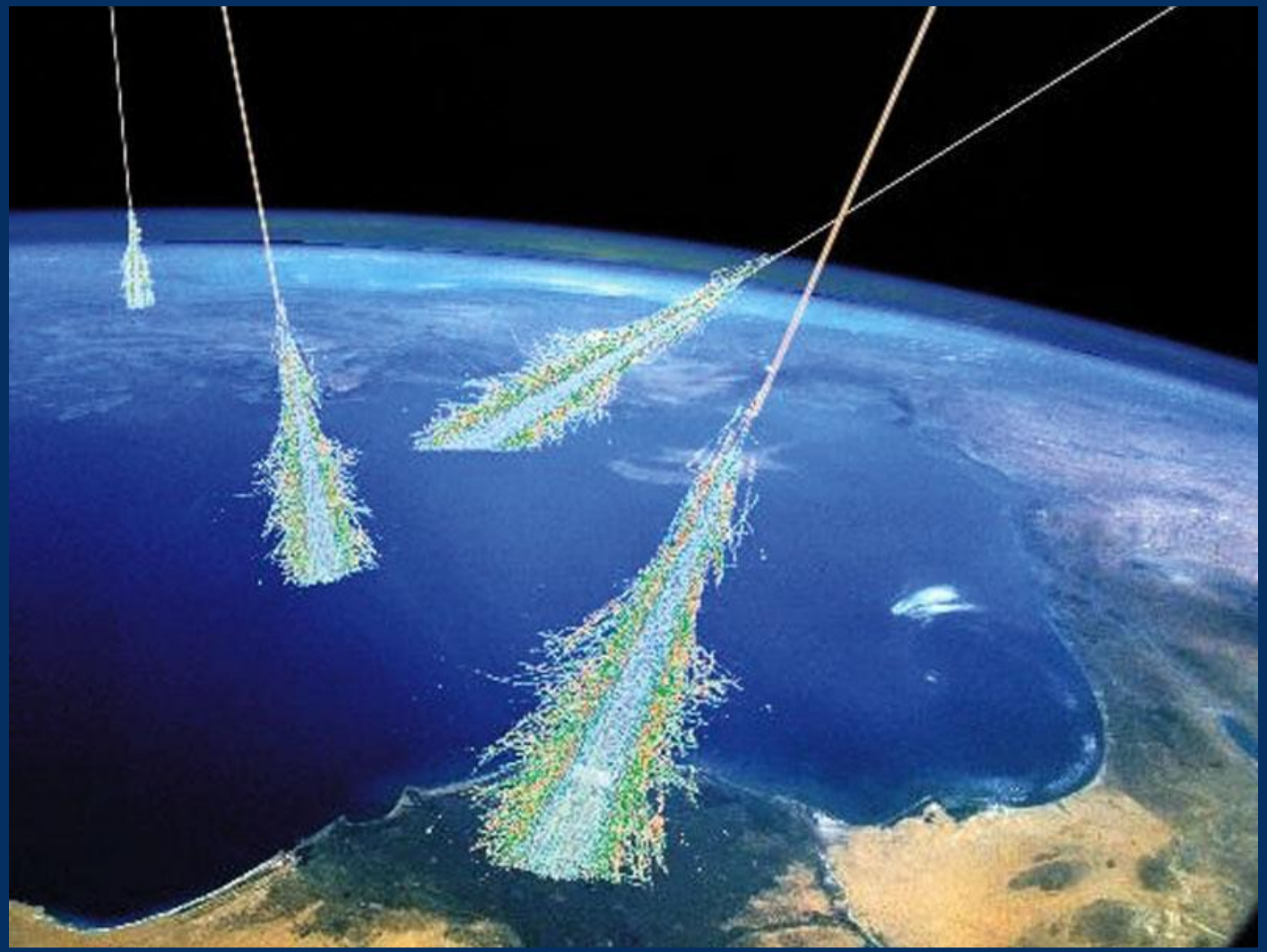
- There are 100,000 aircraft & 1,000,000 people living full time at altitude (thus WGBH's "City in the Sky")
- This implies an annual collective dose from GCR alone of more than 44,000 Person-Sv, greater than Chernobyl
- 68% of the dose is due to neutron radiation
- Air travel is growing exponentially, doubling every 11 to 12 years.

WHAT RADIATION?

- Galactic Cosmic Radiation (GCR, from supernova) High energy protons that create showers of high energy particles
- Solar Particle Events (SPE, from the sun)
- Terrestrial Gamma Flashes (TGF, X-rays created by lightning)
- Other smaller sources (e.g. radioactive shipments, passengers with recent nuclear medicine treatments, etc.)

Galactic Cosmic Radiation

A one-way trip from Chicago to Beijing gives 0.15 mSv (transpolar route).

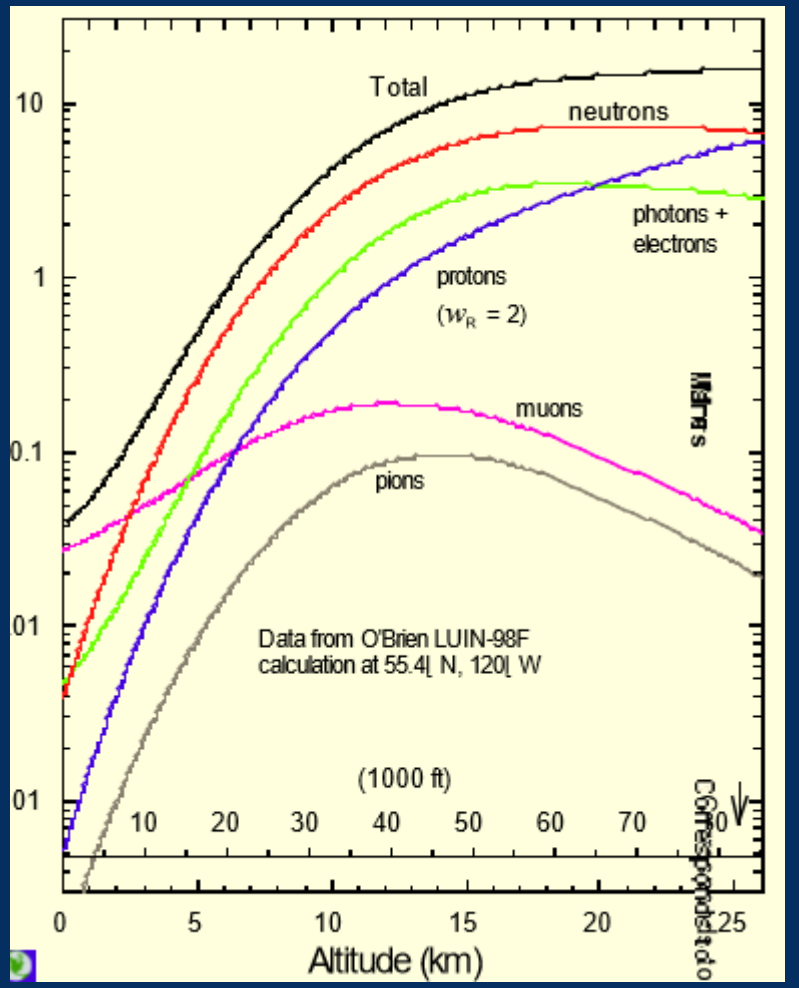


Typical flight levels:

Total dose ~ 9 µSv/h

Neutron dose ~ 7 µSv/h

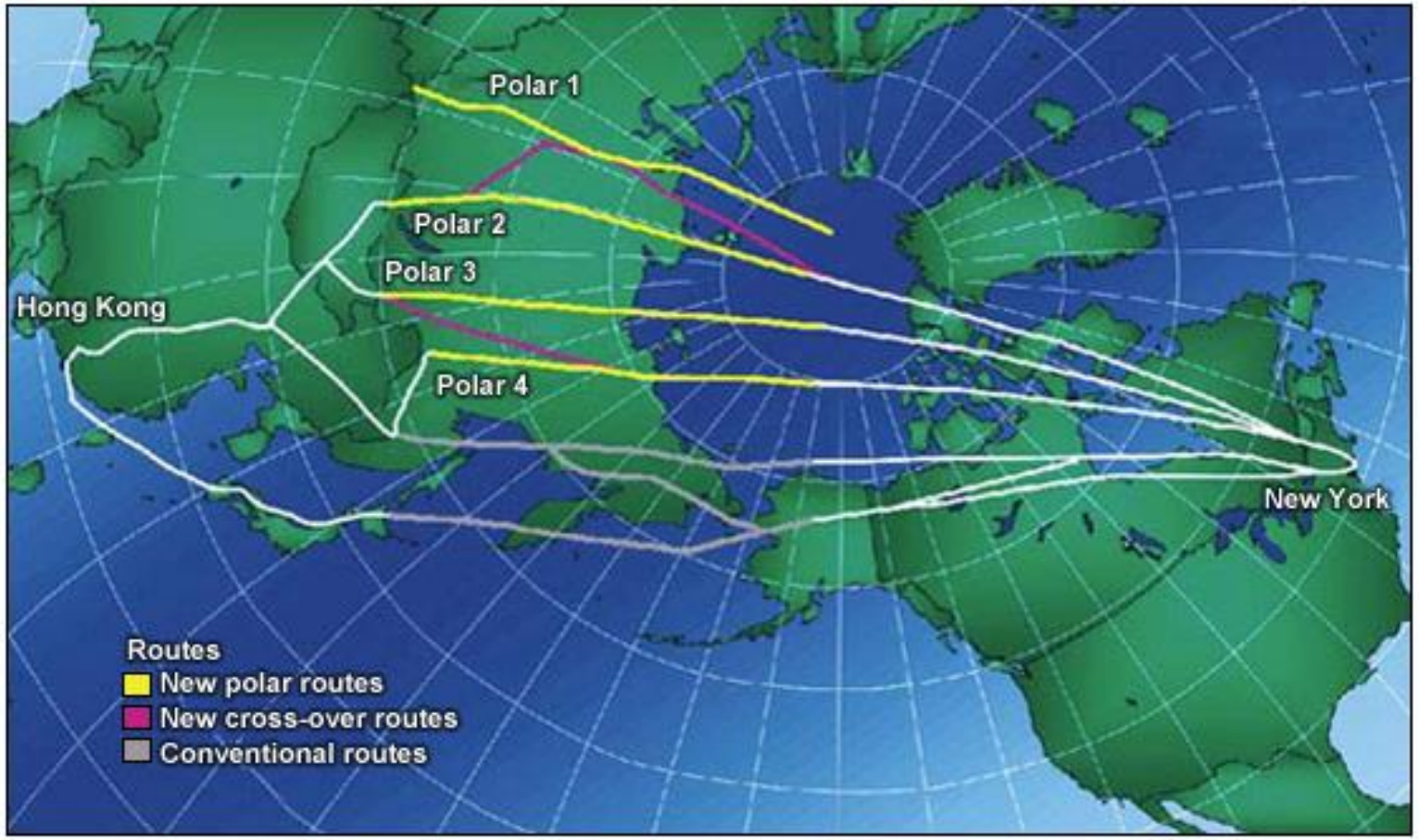
At Sea Level, 10 -20 muons per second pass thru humans



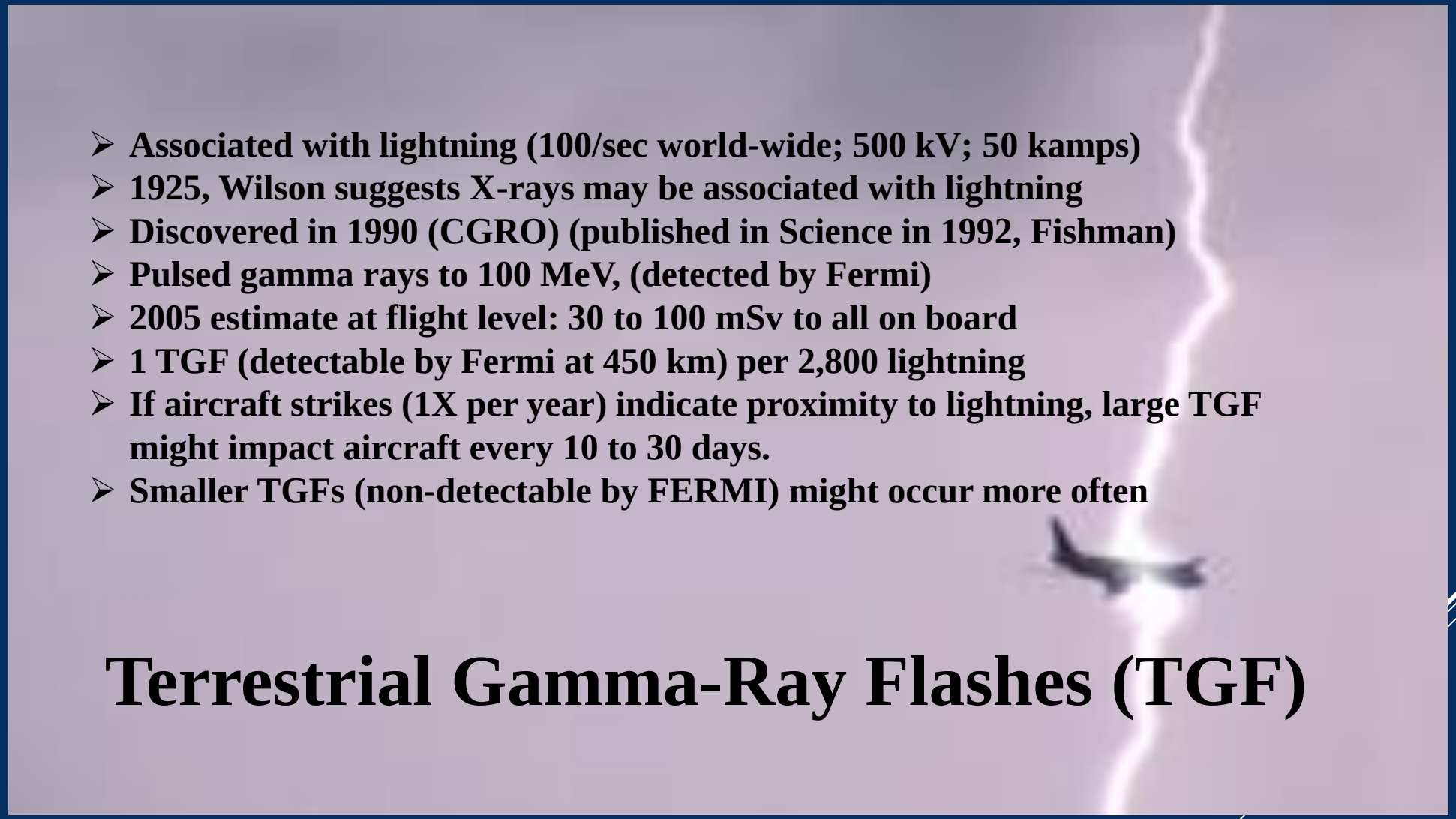
GALACTIC COSMIC RAYS (GCR)

TRANSPOLAR FLIGHTS

- Transpolar (north of 78 degrees lat.) possible after 1992 breakup of USSR
- Preferred by air carriers for least headwinds
- 2001 First passenger flight
- Flights > 16,000 annually (201) and growing exponentially
- Today (quiet sun) 0.15 mSv ORD to PEK
- Seven SPE per year impact Polar Route flights
- SWPC warning (for SPE) experience: 40 false; 63 misses
- 10 mSv solar storm of 1/6/14 to 1/10/14



TRANSPOLAR FLIGHTS (>78° LAT)



- Associated with lightning (100/sec world-wide; 500 kV; 50 kamps)
- 1925, Wilson suggests X-rays may be associated with lightning
- Discovered in 1990 (CGRO) (published in Science in 1992, Fishman)
- Pulsed gamma rays to 100 MeV, (detected by Fermi)
- 2005 estimate at flight level: 30 to 100 mSv to all on board
- 1 TGF (detectable by Fermi at 450 km) per 2,800 lightning
- If aircraft strikes (1X per year) indicate proximity to lightning, large TGF might impact aircraft every 10 to 30 days.
- Smaller TGFs (non-detectable by FERMI) might occur more often

Terrestrial Gamma-Ray Flashes (TGF)

LIGHTNING, ONCE PER YEAR PER AIRCRAFT (100,000 AIRCRAFT, OR 274 TIMES PER DAY)

Christiaan van Heijst: Boeing 747-8 cargo plane at 38,000 feet

AIRCREW MEMBERS ARE THE HIGHEST EXPOSED GROUP OF RADIATION WORKERS

UNSCEAR	Data Period	NFC*	Person-Sv	ACM**	Person-Sv	ACM/NFC
2000	1992	800,000	1,400	250,000	800	57%
2008	2001	660,000	660	300,000	900	136%
	*NFC: rad workers in the Nuclear Fuel Cycle					
	** ACM: aircrew members					
	NFC = 1 mSv (gamma); ACM = 3 mSv (neutron)					
	NFC measured, ACM estimated from GCR only					

OBSERVED HEALTH EFFECTS

- There have been many epidemiology studies of aircrew
- Combining these studies into a “meta-study” shows that breast cancer and melanoma are routinely found to be in excess
- Non-cancer effects are also found (cataracts)
- No other group of radiation workers has an excess of these health effects
- Other risk factors are known to be present, including UV and hormonal changes attributed to diurnal upset
- Radiation is a contributing factor

Annual Exposure Required for 50% POC			
Cancer	ICD-9 Code	Sex	mSv for 50% PC
AML	205	F	1.65
Non-melanoma skin- basal cell	173	F	5.5
Bladder cancer	188	F	6.25
Lung cancer	162	M	7.5
Colon cancer	153	M	11
Breast cancer	174-175	F	12
Bone cancer	170	M	14
Melanoma	172	M	15
Hodgkin's disease	201	M	25
Brain cancer	191	M	35
Rectal cancer	154	M	38
Prostate cancer	185	M	40

IREP POC FOR 30 YEAR CAREER FOR CANCERS FOUND IN AIRCREW

CANCERS FROM: *EPIDEMIOLOGIC STUDIES OF PILOTS AND AIRCREW*
BOICE, J. ; BLETTNER, M. & AUVINEN, A.
HEALTH PHYSICS. 79(5):576-584, NOVEMBER 2000.

EU/UK VERSUS US

- The EU and UK have regulated carriers to control the radiation exposure of aircrew since the 1990s
- Exposure to aircrew of EU/UK carriers is maintained for GCR and (recently) for Solar Proton Events
- Historical data can be added for SPE
- The FAA has never regulated US carriers to control aircrew's radiation exposure
- This has created a 20+ year history with controlled and uncontrolled aircrew exposures

POSSIBLE POPULATIONS FOR STUDY

- US and EU/UK Aircrew serving on commuter airlines (< 1 mSv/a)
- EU/UK aircrew whose exposure is controlled (< 6 mSv/a)
- Uncontrolled US Aircrew, particularly on transpolar/high latitude flights (> 6 mSv/a)
- Exposures above are from GCR alone and do not include SPE or TGF
- Senior US aircrew have received lifetime doses greater than the lower bound of the Japanese survivors
- These exposures are primarily neutron and not gamma
- Other high exposure groups can be considered (e.g. document couriers and corporate aircrew)

CONCLUSION

- Since the 1960s, the failure of the FAA to regulate carriers and require control of aircrew's radiation exposure has created a unique population of workers which can serve to reduce the uncertainty in the quality factor for neutrons and improve our understanding of neutron health effects. The different approach taken by the US as compared to that of the EU and UK has created differences between the aircrew that can be exploited to reduce the uncertainty in our estimates of quality factor for neutrons.