Health consequences of UK nuclear test explosions for Australian participants

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SO, WHAT DO YOU WANT TO BE WHEN YOU GROW UP?
ALIVE... IF IT'S NOT TOO MUCH TROUBLE....
GROUND ZERO 1 MEGATON WARHEAD YOU ARE VAPORIZED
5 MILES YOU ARE COOKED
2 MILES YOU ARE VERY DEAD

World Health Assembly

- Resolution WHA 34.38 22 May 1981
  - The role of physicians and other health workers in the preservation and promotion of peace as the most significant factor for the attainment of health for all
- Resolution WHA 36.28 16 May 1983
  - '… nuclear weapons constitute the greatest immediate threat to the health and welfare of mankind;'

Proliferation growing

Indian women celebrate their country's entry into the nuclear club

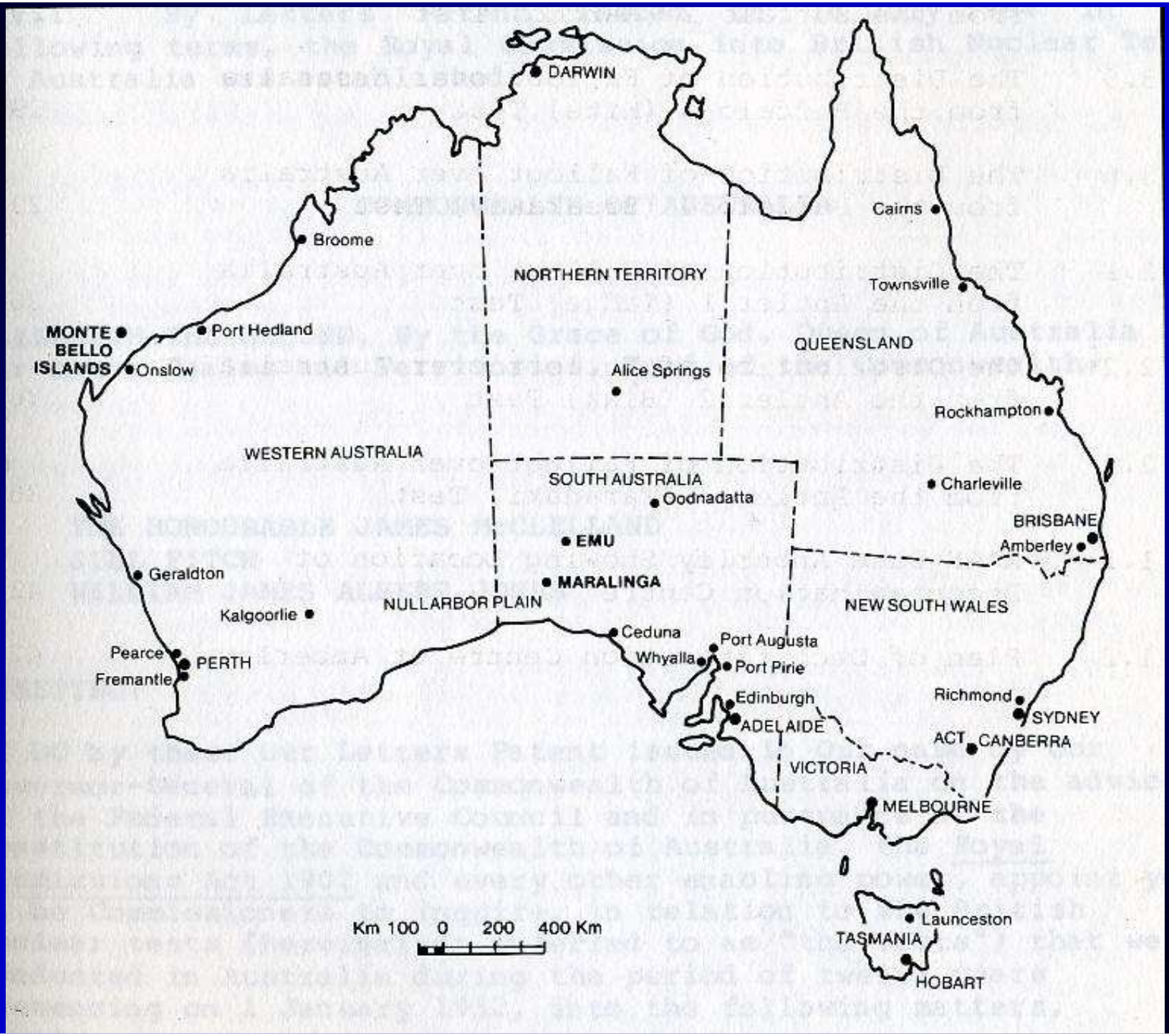
Context

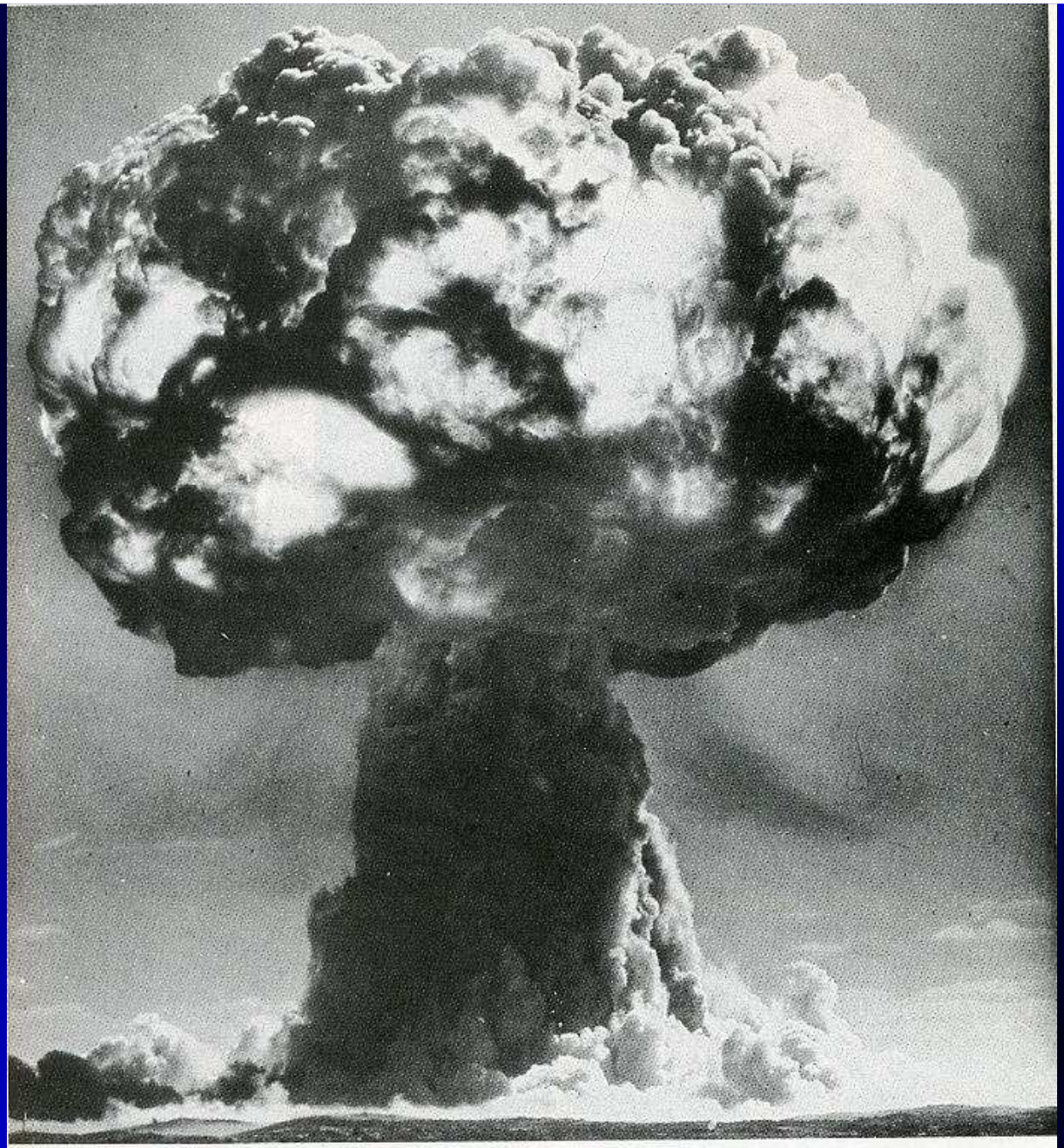
- Nuclear test explosions are for the purpose of developing nuclear weapons, so contributing to the greatest immediate global health threat
- They also of themselves exact a substantial and persisting environmental and human toll
- A Comprehensive Nuclear Test Ban Treaty remains an unachieved and urgent goal – it would prevent immediate harm and ‘significantly impede the development of new nuclear weapons’

Weapons of Mass Destruction Commission. Final Report, Weapons of Terror, 1 June 2006. www.wmdcommission.org

Context - Australia

- Prime Minister Robert Menzies acceded to the British request to host nuclear test explosions by personal decision without consulting Cabinet colleagues or Parliament
- Menzies announcement 18 Feb 1952:
  - "It [the test] will be conducted in conditions that will ensure that there will be no danger whatever from radioactivity to the health of the people or animals in the Commonwealth."
- No public information was made available at the time re extent of fallout over Australia including cities – available information was suppressed


DARWIN
Broome
NORTHERN TERRITORY
Cairns
Townsville
MONTE BELLO ISLANDS
Port Hedland
Onslow
Alice Springs
QUEENSLAND
Rockhampton
WESTERN AUSTRALIA
SOUTH AUSTRALIA
Oodnadatta
Charleville
BRISBANE
Amberley
EMU
Geraldton
MARALINGA
NULLARBOR PLAIN
NEW SOUTH WALES
Kalgoorlie
Ceduna
Port Augusta
Whyalla
Port Pirie
Pearce
PERTH
Fremantle
Edinburgh
Richmond
SYDNEY
ADELAIDE
ACT
CANBERRA
VICTORIA
MELBOURNE
Km 100 0 200 400 Km
Launceston
TASMANIA
HOBART

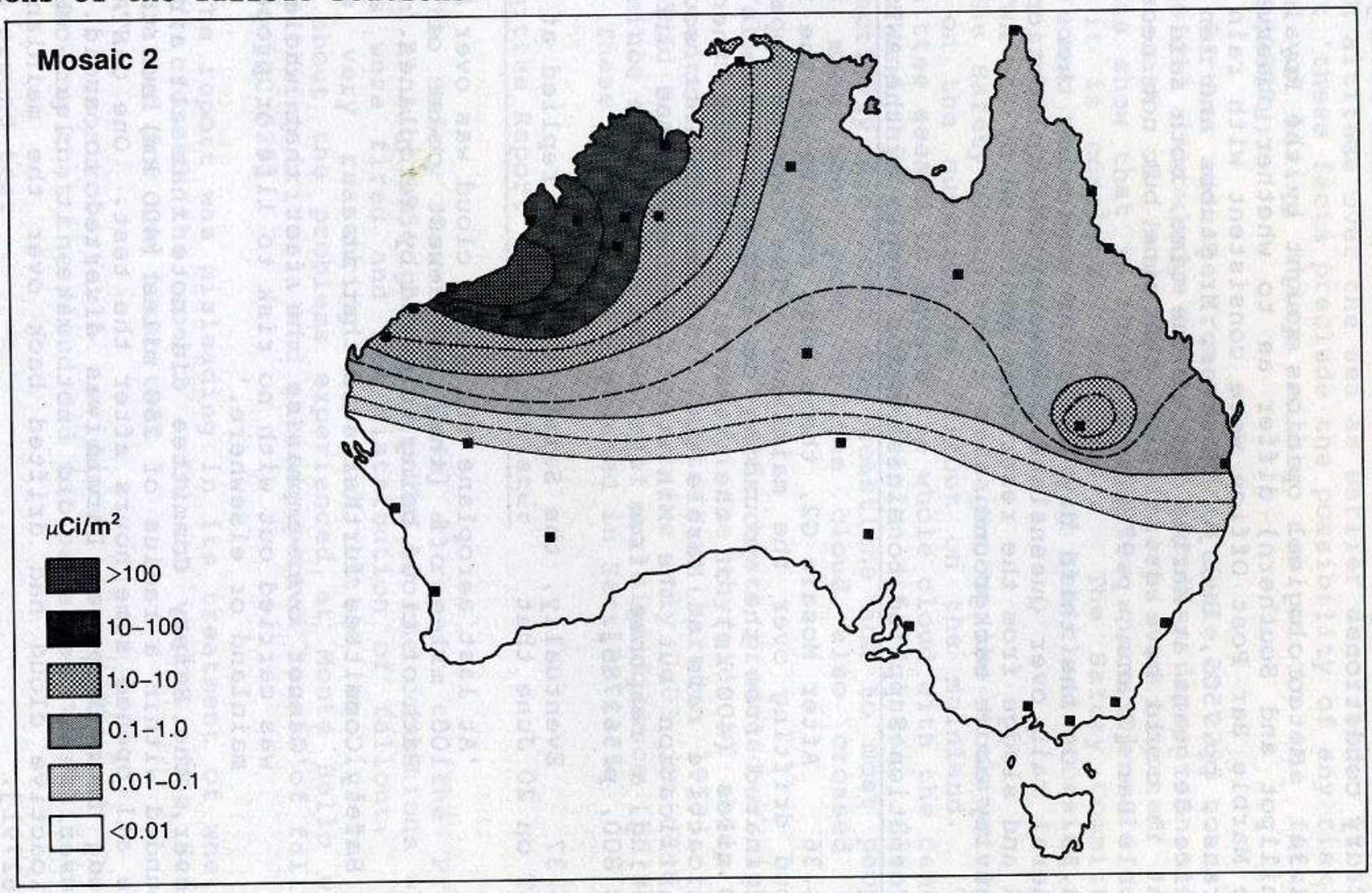


One that went wrong: Mosaic G2. The largest of the Australian tests spread fallout over mainland Australia (*official photo*).

FIGURE 7.4.2

MOSAIC 2

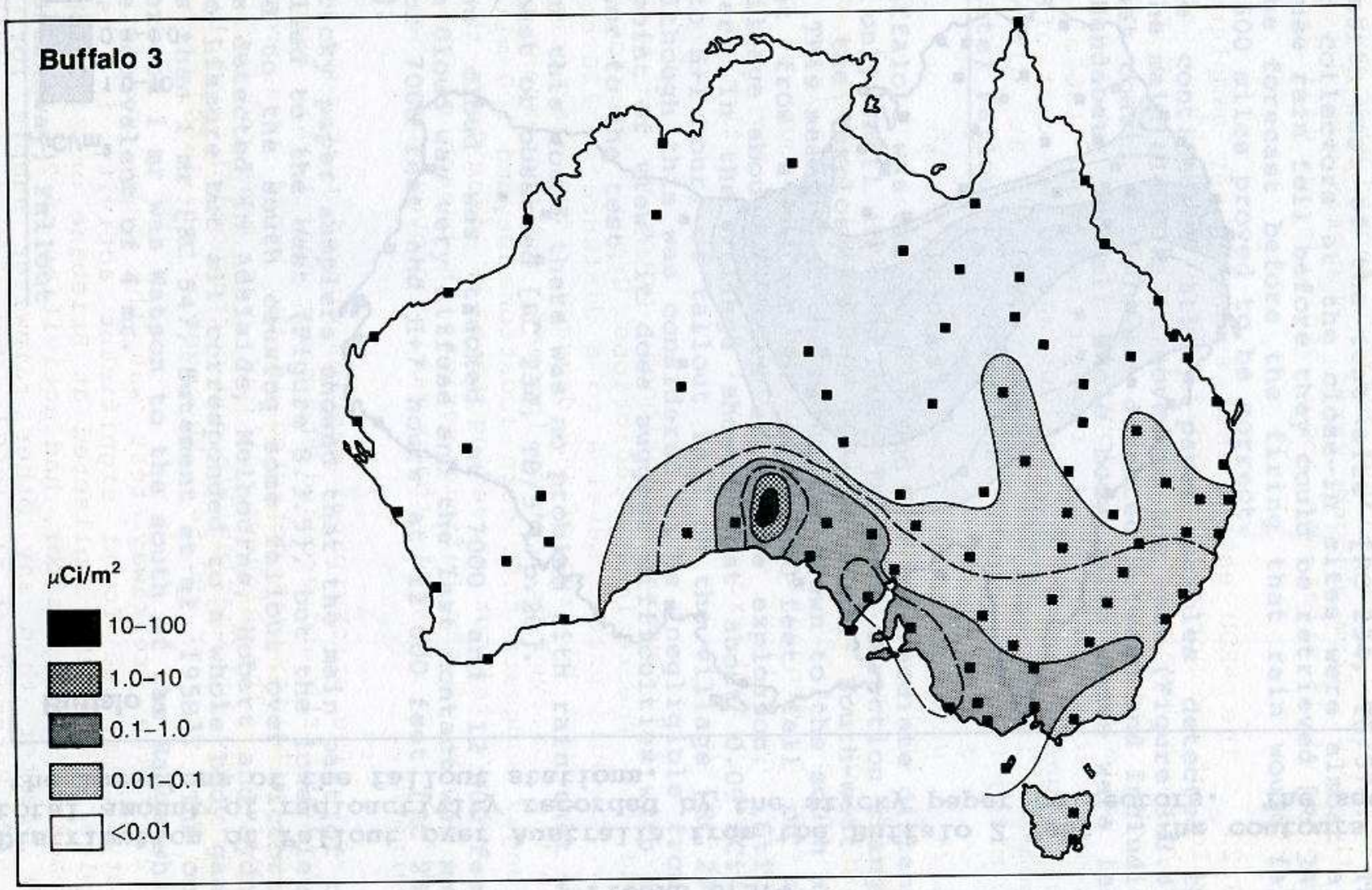
The Distribution of Fallout over Australia from the Test. The contours show the total amount of radioactivity recorded by the sticky paper collectors. The squares show the locations of the fallout stations.



Data from Butement et al. 1957

FIGURE 8.3.5

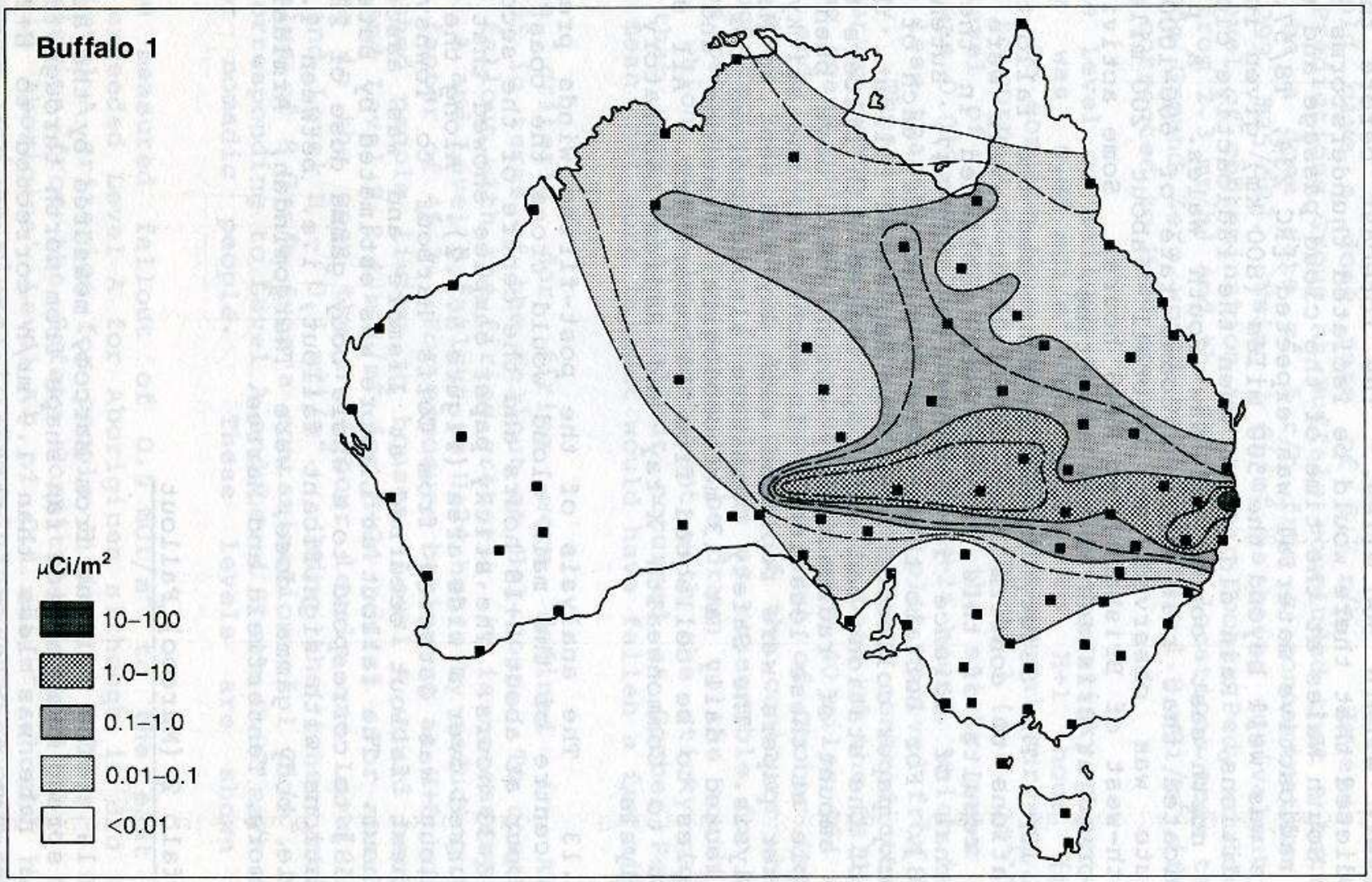
The Distribution of Fallout over Australia from the Buffalo 3 Test. The contours show the total amount of radioactivity recorded by the sticky paper collectors. The squares show the locations of the fallout stations.



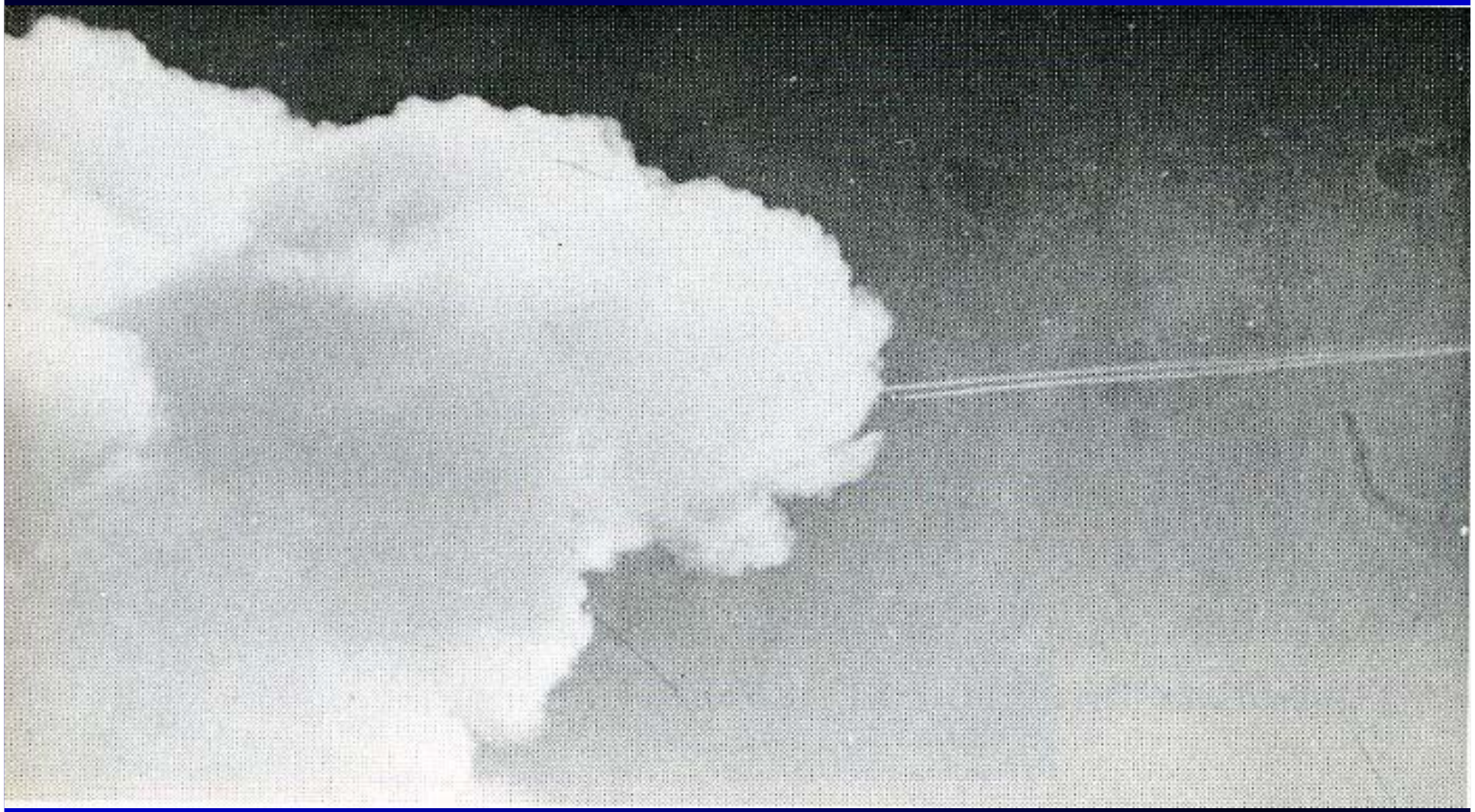
Data from Butement 1958

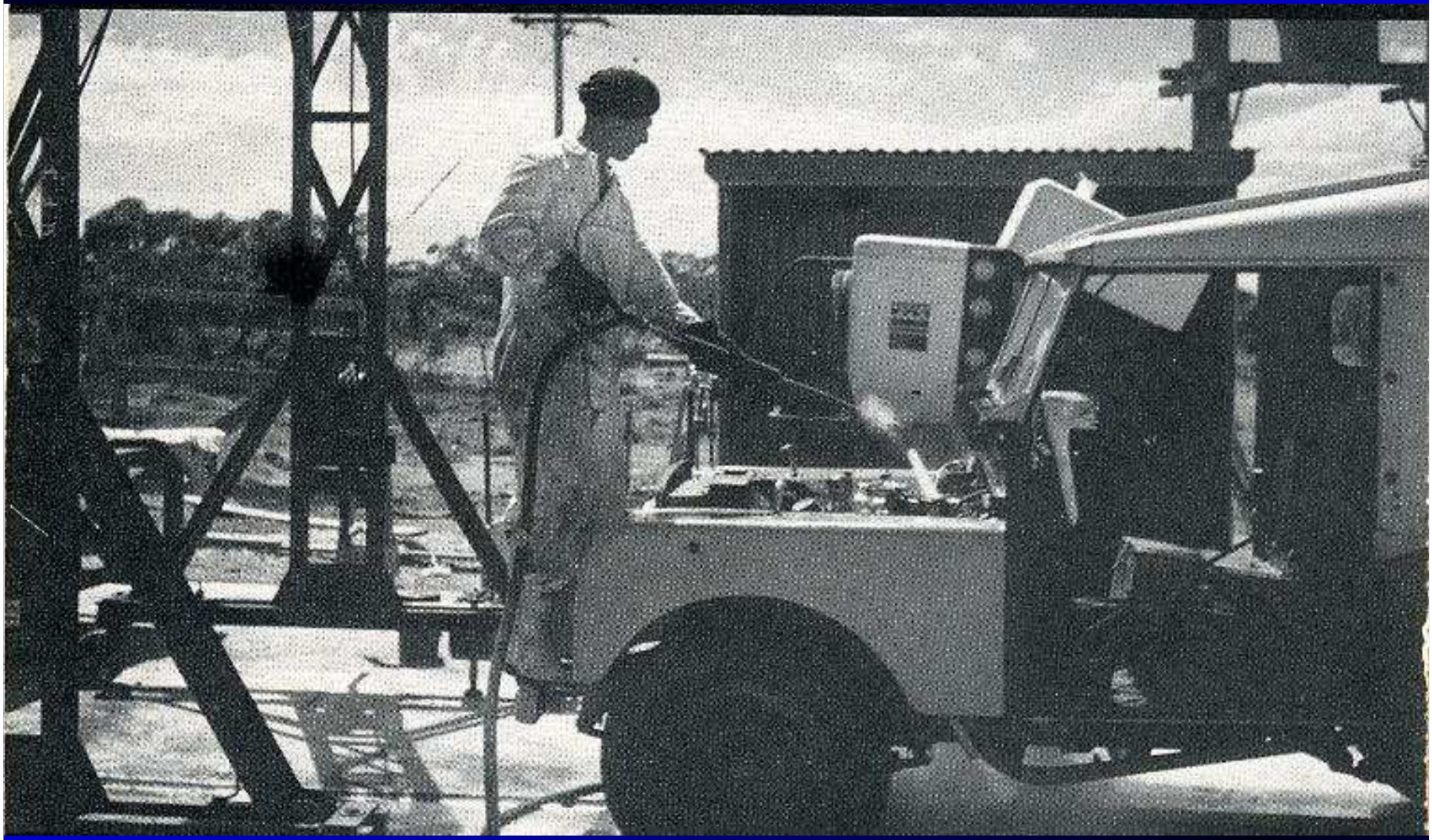
FIGURE 8.3.2

The Distribution of Fallout over Australia from the Buffalo 1 Test. The contours show the total amount of radioactivity recorded by the sticky paper collectors. The squares show the locations of the fallout stations.



Data from Butement et al. 1958





Context

- The highest radiation exposures during the British tests were likely to have been received by Aboriginal people and pastoralists within and near the test range
  - eg exposure to a cloud of ‘Black Mist’ near Wallatinna after Totem 1 at Emu Field 15 Oct 53

Context – minor trials

- Substantial program of nuclear trials 1953-63 - 5 at Emu, almost 600 at Maralinga
- Unlike major trials, Safety Committee had no right to veto
- High degree of secrecy, obfuscation and lack of due process in approvals and conduct
- No Australian ever present at firing
- Phases:
  - **Early** – tests of components or subassemblies eg neutron initiators, high explosives
  - **Vixen A** – tests of spread of radioactive and toxic materials in accidents – petrol fire, combustion in furnace, dispersion by high explosives
  - **Vixen B** – safety trials of effects of accidents (fire, explosion) on nuclear weapons
    - Involved fission reaction but less yield than high explosive
    - ‘a very small atomic explosion’ (RC p 410)

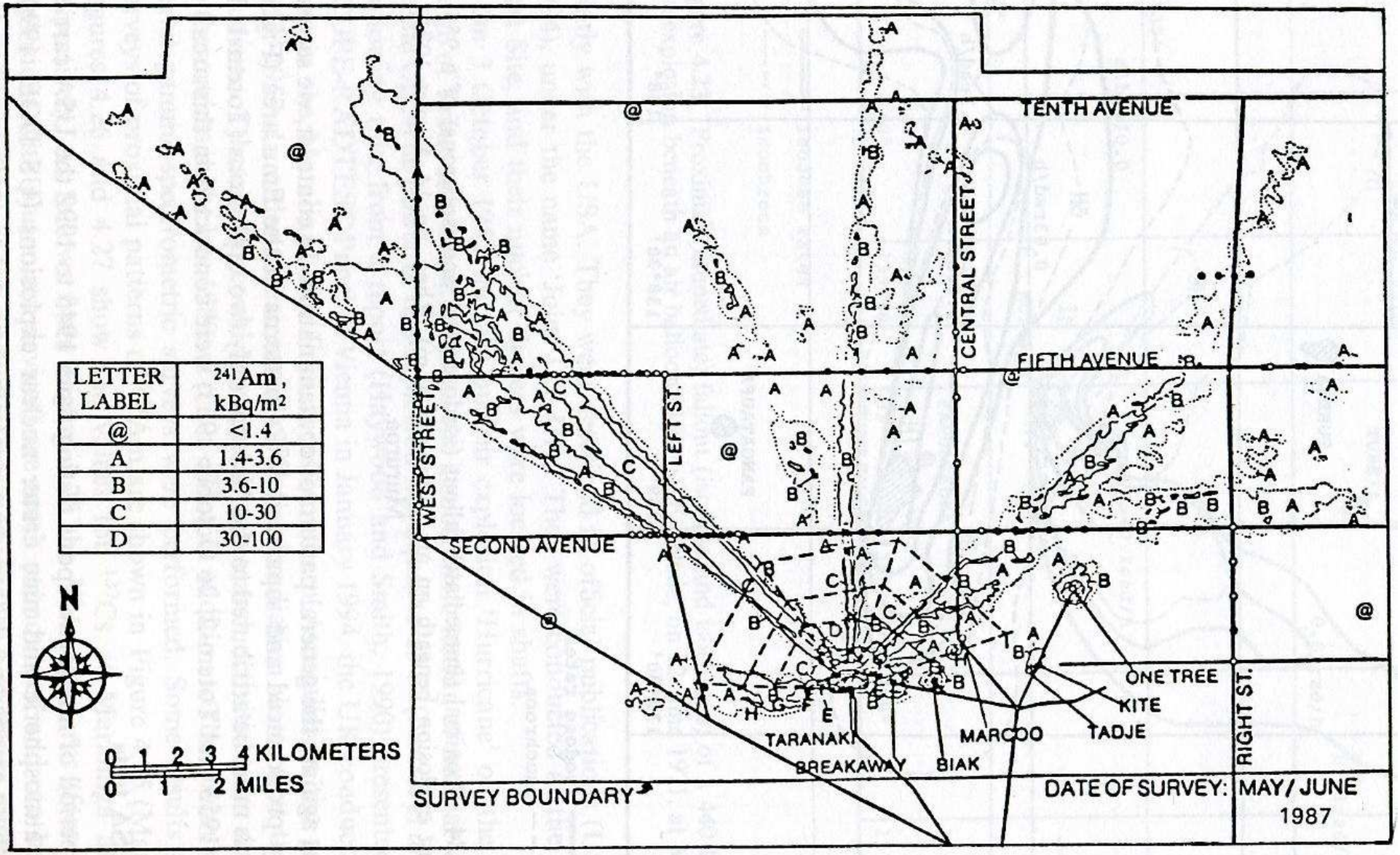


Figure 4.25 Contamination patterns for ^{241}Am in the Maralinga area.

Context – minor trials

- Resulting dispersal of :
  - ***Plutonium* - 24 kg**
    - including est 25-50,000 fragments dispersed in plumes up to 18 km long (with detectable soil contamination up to 37 km)
  - ***Beryllium* - 99.35 kg**
  - ***Uranium* - 8083 kg**
- RC recommendations:
  - Immediate clean-up of Emu and Maralinga fit for unrestricted habitation by Aboriginal owners as soon as practicable
  - All costs of future clean-ups should be borne by the UK government
- Compromised partial clean-up undertaken at cost of >A$104 million (half UK); however half-life of 24,400 y for Pu 239 means some hazard will persist essentially indefinitely
- Near-surface disposal of long-lived waste contrary to government policy
- 450 km^2 unsuitable for permanent occupation

Context – radiation protection

- Radiation protection standards modified repeatedly (always strengthened) strengthened since 1934
- Standards at time of tests were much lower than currently

ICRP dose limits for male workers		
1950	Whole body (at surface) Skin and extremities Critical deep organs	5 mGy/wk 15 mGy/wk 3 mGy/wk
1954	Whole body, blood forming organs, gonads, eye lens Skin and extremities	3mSv/wk 15 mSv/wk
1991	Whole body *Public*	100 mSv over 5 y (not > 50 mSv in 1 y) (~0.4 mSv/wk) *1mSv/y*

Review of Veterans' Entitlements

- Commissioned by Minister for Veterans' Affairs
- 900 page report Jan 2003
- **Current compensation status** :
  - Participation of military personnel in nuclear explosions not covered by *Veterans' Entitlement Act 1986*
  - Compensation for public servants (incl military) is available under ***Safety, Rehabilitation and Compensation Act 1988***
    - Claims determined by civil standard of proof (more probable than not that injury is related to service), however requirements are difficult to meet:
      - Evidence of properly diagnosed medical condition
      - Employment must have made material contribution to contraction, aggravation, acceleration or recurrence of disease

Commonwealth of Australia. Report of the Review of Veterans' Entitlements. Canberra, Jan 2003 (www.veteransreview.gov.au)

Review of Veterans' Entitlements

- ***Safety, Rehabilitation and Compensation Act 1988 (SRCA)***
  - Section 7(1): Employment generally considered to have made a material contribution if it involves exposure (incl to ionising radiation) and a characteristic disease; unless government proves otherwise - 'reverse onus of proof'
  - However this section has been applied to claims for disease or death related to exposure to radiation from nuclear tests only where:
    1. Individual was at test site during or following test
    2. Radiation exposure at test site is confirmed (documented), and
    3. Disease involved is characteristic of radiation exposure

Review of Veterans' Entitlements - SRCA

- Radiation exposure at test site has been determined on basis of government lists of participants, with doses recorded against some names :
  - 1982 UK MOD document 'Overseas Defence Nuclear Experimental Programmes Citizens of Australia (Provisional Issue)', and
  - 1984 Aust Radiation Lab document
- Absence of name and dosage level means exposure at test site not considered confirmed – very few claims meet these requirements
- If these requirements not met, onus of proof is on claimant
- Very few claims have been successful (6 of 204 by 1986 - Milliken R. No conceivable injury. Melbourne, Penguin, 1986)

Review of Veterans' Entitlements - SRCA

- Records of participation and exposure are incomplete – dosimetry data available for 4% of participants in recently completed dose reconstruction study, whereas nominal roll of test participants is reported in Review to contain 15,406 names, including 8035 military and 7371 civilians
- Claimants are now allowed to provide other evidence of test-related radiation exposure, but physical or documentary evidence of exposure to radiation is required – presence at test site alone is insufficient
- Act extended to civilians in 1989
- 1985 Royal Commission recommendation to shift onus of proof to government not yet implemented

Other schemes

- **Special Administrative Scheme (1989)**
  - Response to UK data showing increased leukemia (excl CLL) and myeloma and UK government extending war pensions to cover these
  - Following 1993 follow-up study, UK restricted benefits to non-CLL leukemia within 25 y of test participation – Aust followed in 1995
- **Common law claims**
  - At least 79 claims reported by Review (Jan 03)
  - All 5 heard by courts won by government except for one where anxiety disorder and fear of radiation recognised
- **Act of Grace Scheme**
  - Short 1988-4.9.89 opportunity for some common law claimants to have claims resolved outside courts under SCRA

Comments re current status

- Recommendations of 1985 Royal Commission not substantively implemented
- No current comprehensive, non-adversarial, ready-access compensation arrangements for test participants
- Widespread concern and mistrust re records lost, missing, or not available to participants eg
  - Maralinga hospital records
  - Dosage records for at least 2 military units involved in high-risk tasks of re-entry and recovery removed from National Archives
- Substantial delays at all levels:
  - Collection and reporting of health data
  - Comprehensive participant register
  - Policy decisions and action on independent recommendations

Review Committee assessment

- The 1984 Royal Commission ‘is the only source of an authoritative independent evaluation of the evidence of hazard’
- ‘the evidence is overwhelming that some, if not many of the activities undertaken in the course of the test program were unsafe’
  - Maralinga and Emu Field subject to extensive clean-up
  - Montebello still considered hazardous by govt 50 y later
- There were departures, some serious and some minor, from radiation protection policy and standards

Review Committee assessment

- Specific concerns (RC) cited re:
  - Operation Hurricane (Monte Bello):
    - Divers involved in recovery of landing craft and recovery of moorings
    - Air of unpressurised Lincoln aircraft and ground crews – lack of monitoring devices and instruction
  - Operation Totem
    - Concern re unplanned incidents eg removal respirators in forward areas
    - Negligent for aircrew to fly through Totem 1 cloud without protective clothing, monitoring devices or instruction
    - Radiation exposed tank crew without film badges
  - Operation Buffalo
    - Unplanned incidents and exposure may have occurred
    - Radiation dose records may be incomplete and inaccurate
  - Operation Antler
    - Unplanned incidents

Review Committee assessment

- Australian government forced to accept British assurances on safety without critical Australian examination
- Concept of ‘safe’ level threshold inadequate
- Radiation exposure had increased risk of cancer among nuclear veterans (unable to quantify)
- Sufficient grounds to believe that casualties could have occurred due to combination of
  - Radiation exposure
  - Toxic chemicals used
  - Inadequacies of some controls over the tests

Review Committee assessment

"The British atomic test series was an unparalleled event in Australia's history, in which Australians were exposed to unusual risks from ionising radiation and toxic materials. On the basis of what is now known about the risks of cancers from ionising radiation, and the inadequacies of some of the precautions taken in the conduct of the tests, individuals were put at risk of contracting disease through their exposure in the tests. …

Apart from involvement in wars, other conflicts and overseas deployments, it is difficult to conceive of another Australian military operation in the 20th century comparable to the tests' scale and risk of harm to individuals."

…

Review Committee assessment

"The concerns of the participants in the British atomic tests have been a long-standing issue. There has been an inadequate response by successive governments over many decades. It is a sad fact that the recognition of the unusual hazards faced by the participants has not led to prompt action to ensure a more appropriate compensation arrangement with ready access, given the nature of the hazards."

… it is in the interests of the participants and the Government for the [cancer and mortality] study to proceed as a matter of urgency.

…natural justice for these members is long overdue."

Review Committee recommendations

1. Service with the British atomic tests should be declared as non-warlike hazardous service under Veterans Entitlement Act (VEA)

   – Would provide test participants, at least, with immediate and free health care for all cancers and for posttraumatic stress disorders whilst claims for compensation are made and assessed under the more generous reverse criminal standard of proof (ie unless evidence against relationship of illness to service can be proven beyond reasonable doubt)

   – Development of a nominal roll of participants and dosage estimates need to proceed quickly

Review Committee recommendations

- Government should consider thoroughly addressing concerns of test participants about access to records

2. Government should move quickly to finalise the cancer and mortality study

Cancer and mortality study

- Managed by Dept of Veterans Affairs (DVA), undertaken by Adelaide University
- Includes 10,983 of >16,000 directly exposed to tests – military (64.8%) and civilians employed by construction companies
- Data up to 2001
- Study was due mid 2003; released 28 June 06
- **Volume 1: Radiation dosimetry study**
  - Available exposure data on 4% individuals and modelling used to estimate participant doses by groups
  - Some measurements reported to be available for most occupational groups
  - Compliance with safety standards reported decreased during the test program at least in part due to haste to complete before a possible CTB
  - Australian involvement increased esp last 2 series Buffalo (4 explosions) and Antler (3 explosions) – responsibility for Maralinga Range between and after tests

Cancer and mortality study

- Radiation dosimetry study
  - Estimated mean exposure due to test participation:
    - 2.8 mSv
  - 79% estimated exposure < 1 mSv
  - 4% estimated exposure > 20 mSv
  - Subject to significant controversy within Consultative Forum for studies
  - On basis of estimated doses, 6 of 2456 total cancer cases estimated to be due to radiation

Cancer and mortality study

- **Volume 2: Mortality and cancer studies**
- **Mortality**
  - Test participants compared with general population
  - 934 subjects lost to contact, 23 participants dead but no corroborating evidence
  - Overall death rates similar:
    - Deaths in participants 4233
    - Deaths expected from gen pop 4150
    - SMR **1.02** (95% CI 0.99 – 1.05)

Cancer and mortality study

- Cancer in participants from 1982 – 2001 only, compared with general population
- **Deaths**
  - Cancer deaths 18% higher in participants than expected (statistically significant) SMR 1.18 (95%CI 1.12-1.24
  - Increase in both military (SMR1.17) and civilians (1.21)
  - Deaths from other causes fewer in participants (including less heart disease, cerebrovascular disease – mostly strokes, and external causes (injury, poisonings), suicide
  - Respiratory disease deaths about same as expected

Cancer and mortality study

- SMR >1 for 25/27 cancer types/groupings, significantly so for 6
- SMR <1 for liver (0.93) and kidney (0.99), not significant
- Cancer **cases** (2456) 23% higher than expected
- Significant increases in cases *and* deaths:

	Cancer **deaths** increase in participants (%)	Cancer **cases** increase in participants (%)
All cancers	18	23
Cancers of lip, oral cavity and pharynx	50	41
Lung cancer	20	28
Colorectal cancer	24	16
Prostate cancer	26	22
Radiogenic cancers (8)	43	19

Cancer and mortality study

- Significant increases in participants in ***cases*** *but not* deaths for several cancers (below)
- Significant increase in participants in ***deaths*** but not cases for Unknown primary site (SMR 1.30, 1.04-1.61)

	Cancer cases increase in participants (%)
Esophageal cancer	48
Malignant melanoma	40
All leukemia	43
All leukemia except CLL	61

Cancer and mortality study

- Group-specific effects:
  - Navy:
    - Mesothelioma (asbestos-associated): 26 cases total, 16 of these in navy personnel (almost 3 times expected number)
  - Air force:
    - Melanoma cases (N=71) increased by 2/3, nearly double expected number of deaths
  - Colorectal cancer highest in navy and civilians
- No relationship found between overall cancer incidence or mortality and exposure to radiation, including non-CLL leukemia
- Significant negative relationship between estimated radiation dose and colorectal cancer ($p<0.05$)

Cancer and mortality study

- Putative causes of findings:
  - ? Smoking for cancers of lung; esophagus; lip, oral cavity, pharynx
  - ? Smoking + asbestos for lung cancer
  - ? Asbestos (associated with navy and construction industry for civilians) for mesothelioma, ? colorectal cancer
  - ? Benzene for leukemia
  - ? More Anglo-Saxon ethnicity among participants for melanoma
- Excess melanoma in aircrew in other studies cited
- No data available for asbestos, smoking, or benzene exposure
- Increased smoking rates which would explain increases in different smoking-related cancers are not consistent

Cancer and mortality study - comment

- Limitations include:
  - Retrospective nature
  - Extremely long interval between tests and study conduct
  - Widely geographically dispersed people, name changes
  - Inappropriate comparator of general population ignores ‘healthy worker’ effect – studies of US, UK, NZ test participants use more appropriate matched military controls
  - Cancer study window 1982-2001 misses first 25 y after end of tests and last 5 y
  - Mortality window end 2001
  - Both windows miss highest risk period for those still alive in 2001 (per UK study)
  - Study excludes about 6000 of estimated 17,000 directly exposed persons, including some of likely highest exposed eg Aboriginal
- Note long delay and methodological gaps would tend to dilute observable effects, underlying the significance of positive findings

Cancer and mortality study - comment

- Limitations include (cont'd):
  - Dosimetry data available for only 4% of personnel
  - Estimated doses based on broad groupings
  - Exclusion of non-cancer diseases
- Conclusion that "The increases in cancer rates do not appear to have been caused by exposure to radiation" seems unwarranted – limitations of dosimetry data and estimates (not mentioned in summary) would seem more plausible cause for lack of observed dose-response effect
- Negative correlation with dose and colorectal cancer is implausible
- Variance between summary and body of report:
  - " … some of the biggest uncertainties [re radiation exposure], which are not easy to quantify, are the lack of detailed knowledge of what various participants … were actually doing, where and for how long" Vol 1, p 66

Cancer and mortality study - comment

- Evidence of increased risks is in any case not altered by attribution
- Adverse health outcomes will continue to accrue as remaining test participants age

Cancer and mortality study - comment

Australian participants may well have been exposed to higher risks that UK personnel, based on:

- Extensive personal testimonies
- UK-run program with higher proportion of UK officers, scientists better equipped with PPE and informed incl re risks
- Australians more likely involved in mushroom cloud sampling, forward, recovery and decontamination operations
- Significant increased cancer risk vs general population even with underestimation of increased risk through not controlling for healthy worker effect - matched non-participant service personnel would be more appropriate control group

Cancer and mortality study - comment

- Radiation dose (film badge) data are available for:
  - No more than 4% of Australian test participants
  - 4808/21357 = 22.5% of UK test participants
- May have been increased willingness to harm with less information, protection and monitoring provided to non-UK participants – Fijian, NZ and Australian
  - NZ participants in UK Pacific tests took part in 3 times as many tests as UK personnel (average 3.6 vs 1.2)
- Highly exposed participants will be at higher risk than suggested by studies in which most participants received considerably lower doses
- In current study all doses >50 mSv were assumed to be 100mSv

Cancer and mortality study - comment

- **High exposures**
  - Royal Commission documented individual exposures up to 300 mSv
  - About 900 people involved in clean-up after first Monte Bello test 1952 - estimated that 31 received 30 - 50 mSv (p125-6)
  - Aircraft crews in unpressurised Lincoln bombers spent up to 55 min in fallout clouds without proper protective clothing, instruction or radiation monitoring devices
    - They probably received higher doses than the crews of pressurised Canberra bombers who received gamma doses of up to 210 mSv during flights (p207-8)

Cancer and mortality study - comment

- Example of discrepancies re dose estimates (current Australian dosimetry study):
  - Members of Joint Service Training Unit recorded via film badges receiving **20 mSv** on each of days 66 and 67 after Hurricane Test at Monte Bello while wearing protective clothing and undertaking sample collection
  - **19.0 mSv** estimated doses accrued for General Engineering Support in forward areas, commencing on day of explosion, frequently without protective clothing for :
    - 4 Buffalo tests from days 1-50, and
    - 3 Antler tests from days 1-115 ie total 165 days

- NB Royal Commission concluded (1985):
  - 201. “Because of the deficiencies in the available data, there is now little prospect of carrying out any worthwhile epidemiological study of those involved in the tests nor of others who might have been directly affected by them.”
  - Comment: difficulties in retrospective dosimetry are even greater than for cancer and mortality

Cancer and mortality study - comment

- Litany of 50 years of :
  - Lack of recognition of hazardous service despite clear evidence of risk
  - Lack of fair, non-adversarial, accessible compensation provisions
  - Failure to implement independent recommendations eg 1984 Royal Commission, 2003 Review of Veterans' Entitlements
  - Inadequate transparency and access to relevant health and exposure documentation held both in Australia and UK
  - Lack of prospective, ongoing, long-term health follow-up with appropriate controls from outset

Health care for test participants

- Announcement by Minister Bruce Billson 28 June 06:
  - All military, public service and civilian participants in tests 1953-63 will have access to care for all cancers
    - White Repatriation Health Card – For Specific Conditions
- Eligibility: working, or visitor in at least one of testing areas while tests were conducted or present in a test area within 2 y after ‘the relevant explosion’
- Comment: Partially grasps obligation to definitively, 50 years later, finally provide natural justice for remaining test participants for the remainder of their lives
- Major unmet needs in addressing indigenous dispossession, residual contamination and inadequate cleanup

‘By the time they complete the study, none of us will be left.’

‘Justice delayed is justice denied.’

Thank you!

Back-up

Nuclear test participant studies - UK

- N=21,357 military and male civilians (4%) participated in UK atmospheric nuclear tests compared with N=22, 333 military and Atomic Weapons Establishment controls matched on various characteristics
- 3 Australian sites, Malden and Christmas Islands
- 3 successive studies covering 1952 till 83, 90 and 98
- Cohort ~85% complete, incomplete cancer data 94-8
- Funded by MOD, conducted by NRPB

Darby SC, et al A summary of mortality and incidence of cancer in men from the United Kingdom who participated in the United Kingdom's atmospheric nuclear weapons tests and experimental programmes. BMJ 1988;296:332-8.

Darby SC, et al. Further follow-up of mortality and incidence of cancer ... BMJ 1993;3071530-5.

*Muirhead CR, et al. Follow up of mortality and incidence of cancer 1952-98 … Occup Environ Med 2003;60:165-72.

Nuclear test participant studies - UK

- Mortality and incidence 27 types of cancer 1952-98; dosimetry (for 4808) based on film badges and potential for exposure based on duties
- 1716 / 4808 (36%) non-zero gamma dose recorded – mean 9.9 mSv
- Deaths: 2089 incl 785 cancer, 16 leukemia
- Cancer cases: 2641 incl 67 leukemia
- Main findings:
  - No differences in overall mortality or cancer incidence
  - Significant healthy worker effect (waning over time), with reduced deaths from all causes except accidents and violence
  - Increase non-CLL leukemia: RR 1.83 (90% CI 1.15 - 2.93) SMR participants 106 vs controls 58

Nuclear test participant studies - UK

- **Leukemia**
  - CLL not radiation related - as expected, effect greatest if CLL excluded
  - Significant excess among participants over full FU period for chronic myeloid leukemia (CML): 12 cases vs 4

- **Multiple myeloma**
  - Last study undertaken because of concerns raised by British Nuclear Test Veterans Association
  - RR myeloma death up to 1990 2.05 (90% CI 0.99-4.30) over full FU period RR 1.14 (90%CI 0.74 -1.74) – trend does not justify conclusion of 'no evidence of increased risk'
  - Decline in RR with extended FU may indicate time-limited nature of increased risk

Nuclear test participant studies - UK

- 27 cancers (≥ 10 y after first participation)
  - Significant excesses in participants for liver and prostate cancer in addition to leukemia (2 – 25 y after test participation)
  - Significantly lower incidence only for kidney cancer

Cancer type	**Relative risk (RR)**	**90% CI**
Liver	1.99	1.19 - 3.38
Prostate	1.22	1.04 – 1.43
Leukemia 2-25 y	3.17	1.63 – 6.31
Non-CLL leukemia 2-25 y	3.97	1.73 – 9.61
Kidney	0.74	0.57 – 0.96

Nuclear test participant studies - UK

- Cancers of lung, bladder, liver associated with radiation in other studies eg Japan
- Decline in RR between FU to 1990 and 1991-8 (as for myeloma) also observed for deaths due to cancers of:
  - Bladder: N=29:11, RR 2.85 (1.51–5.47)

    → N=23:23, RR 1.13 (0.67-1.29)
  - Lung
  - Tongue, mouth and pharynx
- May be due to decline in excess risk after several decades, limited time period or incomplete case ascertainment

Nuclear test participant studies - UK

- Dose –response effect
  - No significant trends for most cancers but statistical precision low
  - Myeloma death significantly more common in participants with a recorded gamma dose than those without recorded dose (Table)
  - Weaker but consistent trend for incidence: RR 4.91 (0.94-26.8), P=0.08
  - Similar trends in myeloma mortality with dose (P=0.094) and myeloma incidence with dose (P=0.12)
  - Authors' attribution of myeloma findings to chance seems unwarranted

	Monitored participants with recorded gamma dose	Monitored participants with no recorded gamma dose	RR (90% CI)
Myeloma SMR	210	64	16 (1.74-314) P=0.01

Nuclear test participant studies - UK

- Substantial healthy worker effect:
  - Non-CLL leukemia rates in controls significantly lower than national rates (SMR 58 to 1990, 59 for 1991-8)
  - Mortality in participants and controls for all causes, all cancers and all other diseases were significantly lower than national rates (mortality for all accidents and violence were higher)
  - Effect wanes over successive decades:
    - All cause participant SMR to 1990 = 84
      1991-98 = 95

Nuclear test participant studies - UK

- **Limitations:**
  - Retrospective rather than prospective study design
  - Cohort incomplete
  - FU to age 85 y rather than time of death
  - External gamma dosimetry available only for minority; no estimates on completeness even when available
  - No data on neutron exposure or internal exposure from inhalation and ingestion
  - Limited consideration of hot spots or most highly exposed eg
    - Canberra ‘sniffer’ aircraft flying through mushroom cloud minutes after explosion estimated to involve mean dose of 50.5 mSv per man per test

      » Darby SC et al. Oxon, NRPB, 1988
    - Those involved in decontamination

Nuclear test participant studies - UK

- Participants employed by Atomic Weapons Establishment or directly involved in minor trials thought most vulnerable to undocumented radionuclide inhalation or ingestion (N=1041)

- Significant finding in this group of increased rate of all cancers except leukemia and myeloma (N=171)
  - RR **1.21** (90% CI 1.01-1.46)

    - Included in supplementary tables,not mentioned in published paper

Nuclear test participant studies - NZ

- Blinded controlled follow-up for up to 30 y (1957-87) for NZ participants in Operation Grapple
  - 1957-8, 9 of total 21 UK atmospheric nuclear explosions
  - Christmas and Malden Islands
  - NZ ships stationed 35 – 280 km from ground zero
- Participants: N=528, FU 94% complete
- Controls: N=1504 Navy personnel serving at same time not participating in tests, FU 91% complete
- Average no. tests attended: 3.6; at least 24% attended ≥ 5 tests *(NB. UK average 1.2 tests per participant)*
- NZ cancer registry >90% complete since late 1950s and ~100% complete since 1972

Nuclear test participant studies - NZ

Cause of death, cases	Relative risk participants vs controls	90% CI, P value
Total, 70:179	1.08	0.85-1.38, P=0.29
Causes other than cancer, 44:127	0.96	0.71-1.29, P=0.59
Cancer, 26:52	1.38	0.90-2.10, P=0.09
Hematological cancer, 7:6	3.25	1.12-9.64, P=0.02
Leukemia, 4 (incl 1 CLL):2	5.51	1.03-41.1, P=0.03

Participant mortality slightly higher than expected from national mortality (SMR 1.15), controls similar to expected (SMR 1.06)

Only 1 myeloma death in participants (after FU period)

Pearce N, Prior I, et al. BMJ 1990;300:1161-6

Nuclear test participant studies - NZ

- No publicly available information on gamma radiation doses
- No data available (for any UK test participants) on neutron or internal radiation due to inhalation or ingestion
- Local fallout and induced radioactivity occurred, test-induced rainout events may have occurred
- Exposures of non-British personnel (NZ, Fiji) may have been different to UK personnel:
  - NZ 3.6 tests per participants cf UK 1.2
  - Scientists and officers in special bunker for test; others on land or deck with minimal or no protective equipment

IPPNW / IEER. Radioactive heaven and earth. New York, Apex Press; London, Zed Books, 1991:123-32

Nuclear test participant studies - USA

- Of estimated 205,000 military personnel participated in US atmospheric nuclear tests 1945-62, <1% received doses ≥ current occup limit of 50 mSv (external gamma radiation) over 1 y
- Mortality from first exposure to 1996 for N=1010 with highest external gamma doses compared with N=2870 Navy veterans who received minimal radiation doses
- 300 deaths in highly exposed, 11 cases lymphopoietic cancer
- All cause mortality increased:
  - relative risk (RR) **1.22** (95% CI 1.04 -1.44)
- Lymphopoietic cancer deaths increased:
  - RR **3.72** (95%CI 1.28-10.83)

Dalager NA et al. J Occup Env Med 2000;42(8):798-805

Nuclear industry workers 1

- 15 country retrospective cohort study of cancer mortality auspiced by IARC
- Largest such study ever conducted
- Workers involved in fuel enrichment or reprocessing, reactors, weapons or isotope production (excl uranium mining)
- 407,391 workers (90% male):
  - employed ≥ 1 y
  - monitored for external photon (X and gamma) radiation
  - > 90% whole body dose from external photons rather than neutrons or internal exposures
- Total FU 5.2 million person y

Nuclear industry workers 2

- Doses to colon used for all and solid cancer, active bone marrow for leukemia analyses, lagged by 2 y for leukemia and 10 y for other cancers

- Doses:
  - Average 19.4 mSv
  - 90% < 50 mSv
  - < 0.1% > 500 mSv

- Total deaths 6516 from cancer other than leukemia, 196 from leukemia excl CLL

Nuclear industry workers vs Japanese bomb survivors* 3

Cause of death, N Workers *Survivors*	Excess relative risk per Sv	95% CI
All cancers excl leukemia, 5024	0.97	0.14 -1.97
Solid cancer, 4770 *3246*	0.87 *0.32*	0.03 - 1.88 *0.01 – 0.50*
Leukemia excl CLL, 196 *83*	1.93 *3.15^* *1.54”*	<0 – 8.47 *1.58 – 5.67^* *-1.14 – 5.33”*
Lung cancer	1.86	0.26 – 4.01

**Men aged 20-60 at time of exposure*

^Assuming linear dose response with no threshold

“ Assuming linear-quadratic response

Nuclear industry workers 4

- Mortality from all cancers except leukemia – central estimate 2-3 times higher than linear extrapolation from atomic bomb survivors
  - Current recommended 5 y occup dose limit of 100 mSv → 9.7% (1.4 - 19.7%) increase in cancer excl leukemia
  - For leukemia excl CLL 100mSv → 19% (<0 - 84.7%) increase

Cardis E, et al. BMJ 2005 (29 June 2005)
BMJ,doi:10.1136/bmj.38499.599861.EO