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Radiation Measurement Experiences and Lessons to be Learned in Response to the Fukushima NPP Accident [*the abridged version*]

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Obligatory Caveat

The opinions expressed within this presentation are purely my own; especially those coming after a few beers this evening.

My employer, my wife and mother have all been given to opportunity to review this presentation. None of them will put in writing their approval.

Preparation for this presentation

- **Previous experience at things like this**
  - **TMI - On-site 36 hours after the accident, for the next ~1mo**
    - Managed the Radiation Management Corporation team responding to this accident
      - Mobile WBC at TMI during the accident and for the next many months
      - Operated mobile gamma spec laboratory – did most of the effluent measurements from unmonitored release points
      - On-site counting lab during the decon project
      - Off-site environmental monitoring program – including 1 truck of chocolate per day
  - **Chernobyl – several trips to Ukraine**
    - Supplied 7 mobile WBC in support of Population monitoring + 2 more to the plant
    - Worked with the German team performing these population studies
- **Published or on-line literature about Fukushima radiation measurements**
  - **Extensive data available about this accident – some of it is correct and useful**
    - much of it in Japanese; electronic translation software is still only marginally understandable
- **Health Physics Society Professional Development School - Fukushima**
  - **This is a small part of a lecture I gave as one of the instructors – *ALARA-specific portions***
- **Personal experience in Japan**
  - **Part of AREVA initial response team first 4-5 months**
  - **Since then assisting our Japan office in business development efforts**
  - **21 trips to Japan since the accident; 6 mo in Japan; 300mRem – 290 from 1.3 mo on airplanes**
  - **My major project since the accident**
  - **Our team prepared many concepts and proposals, some of which were actually accepted**

Key points from this presentation

- Purpose is to inform, educate, and learn for the future
- Yes, some things could have been improved, but the things that the professionals responding did were very good, considering the circumstances
- Real doses have been quite low, even among workers
  - Good Rx design, Rx operations and response, HP response
- Imagined doses and associated harm are high, among workers and population
- ALARA should apply to both real and imagined dose, and the economic consequences of imagined dose/activity. It is critically important to the success of the NPP industry
  - Education, dissemination of reliable quality information

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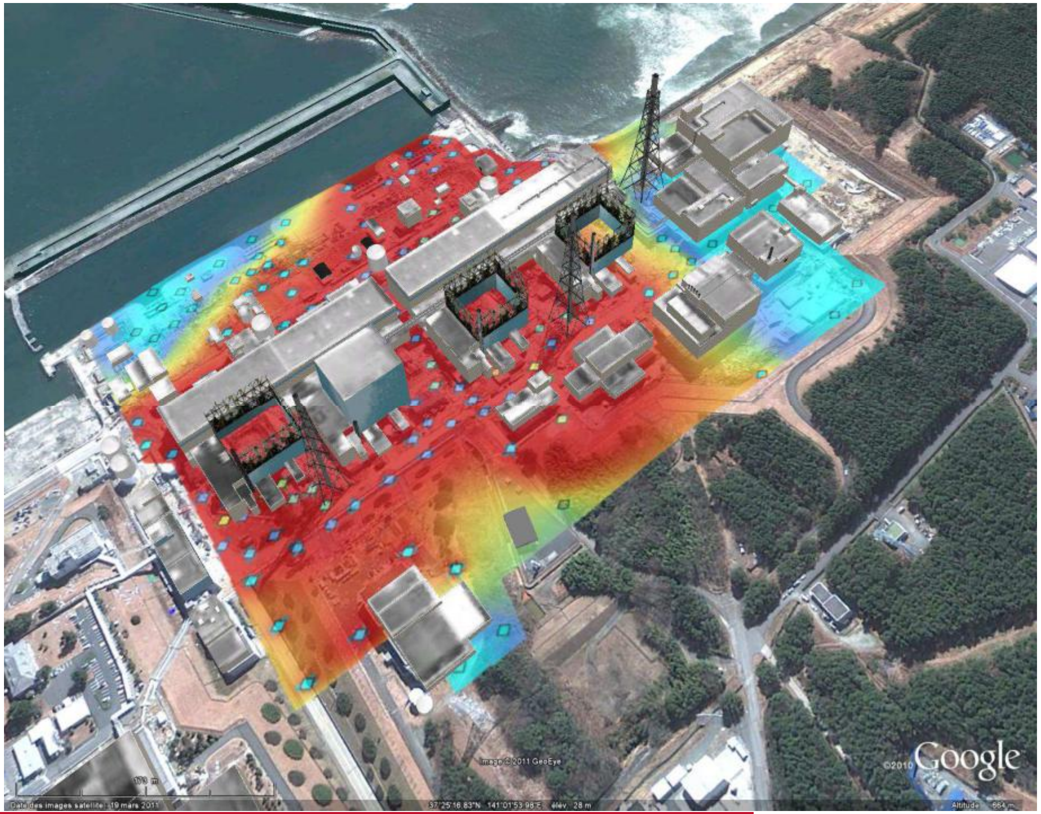
EARLY PHASE
ON-SITE ISSUES

generally as Canberra input to the AREVA response effort

Mapping radiation levels on-site

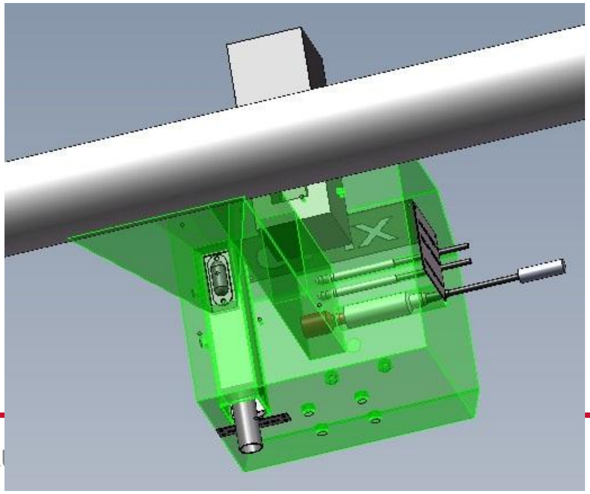
- A few weeks after the accident, the AREVA team prepared the first map to support the water treatment facility installation and operation
- During the pre-installation inspections workers carried the Colibri doserate meter with them for the first few trips
  - With integral GPS and automatic data logging

- Map created using CEA radiological mapping algorithms licensed by Geovariences
- Used by AREVA team for dose optimization planning
  - Where to locate the water processing equipment
  - What routes for personnel egress



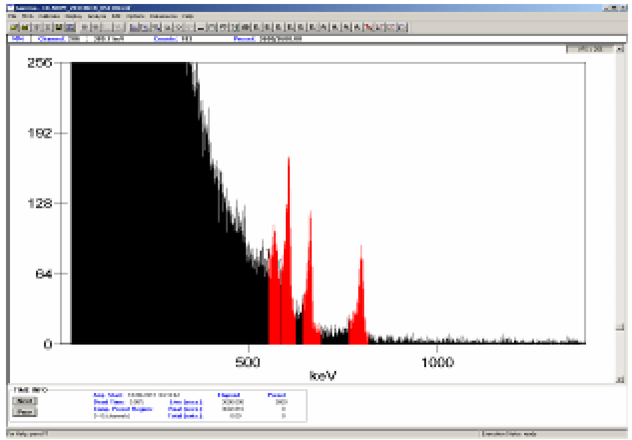
AREVA-Veolia-Canberra water processing system

- 75 days from conception to operation !!
- Instrumentation [Canberra part]
  - 5 spectroscopy measuring station, each with dual CZT probes
  - MCNP calibration – quantitative results
    - ISOCS Characterizations now in progress
  - 6 wide dynamic range dose-rate monitoring points
  - Shielding for all sensors
  - Remote monitoring software for setup, adjustment, viewing results, data archiving
  - WAN on site, to TEPCO Tokyo, and to France

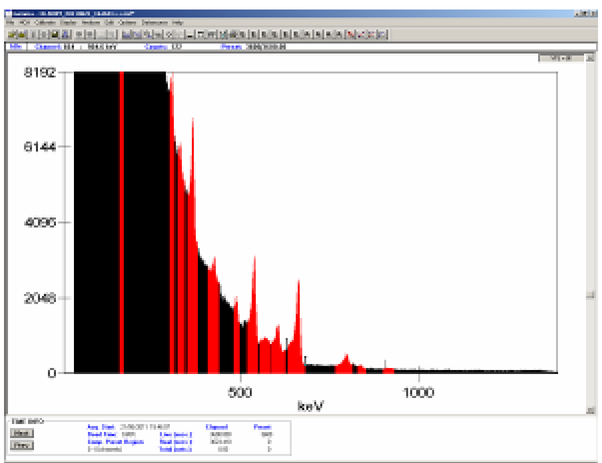


Activity determination via CZT gamma spectrometry measurement channels

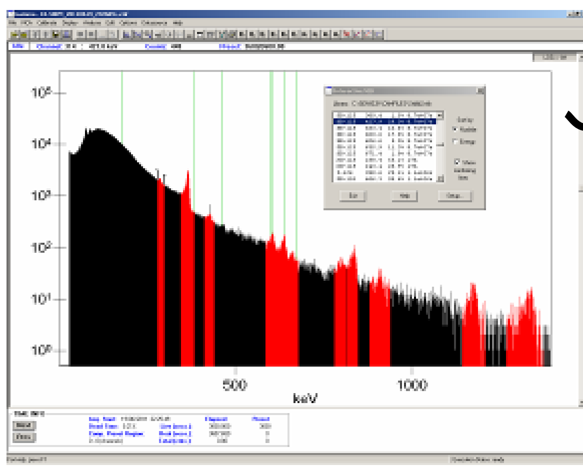
XI-10 CZT 500



Cs134 and Cs137

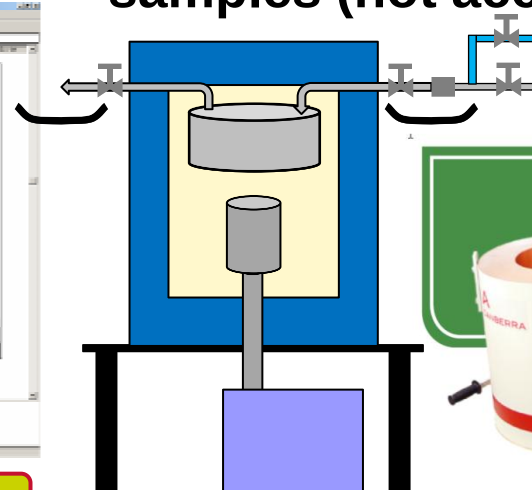


I131 and Sb125



I131 Sb125 and Co60

- Unit DF was higher than expected
- Output concentration too low to be measured with CZT
- Proposed more sensitive automatic system instead of grab samples (not accepted)



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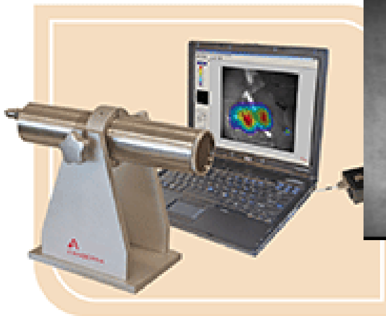
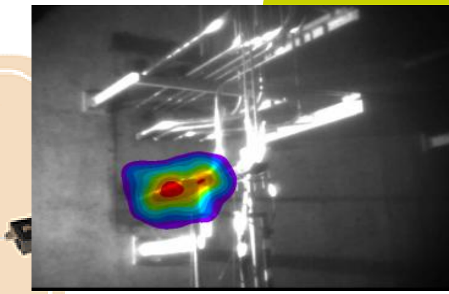
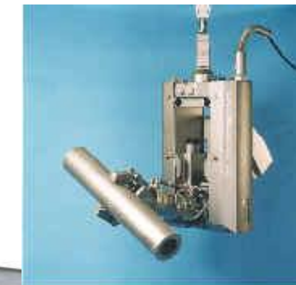
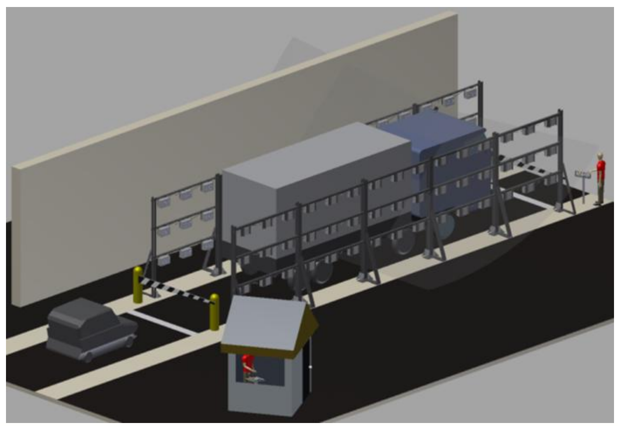
Many other proposals, as part of the AREVA team
technically interesting, but not profitable

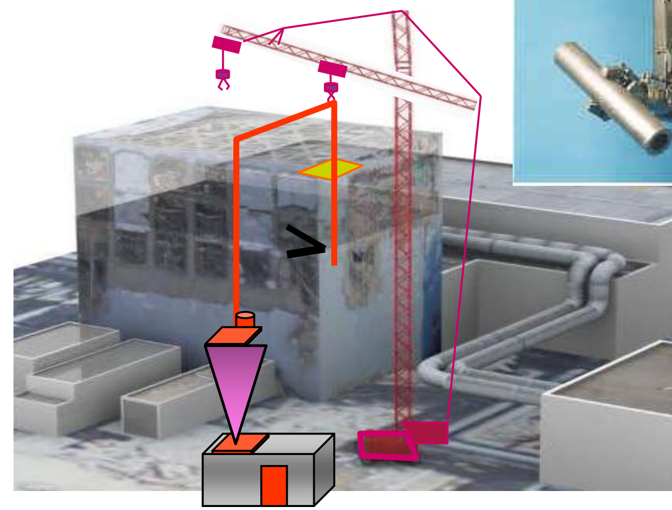


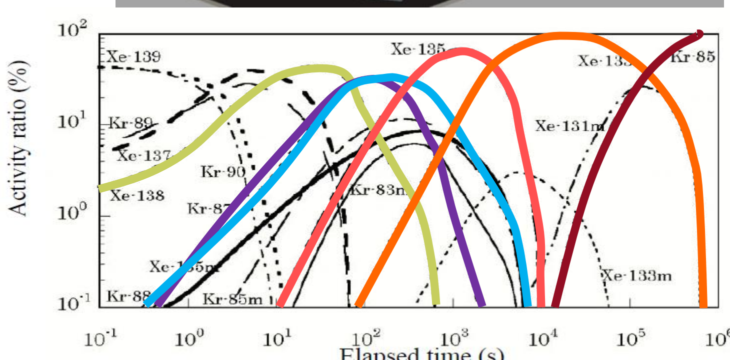


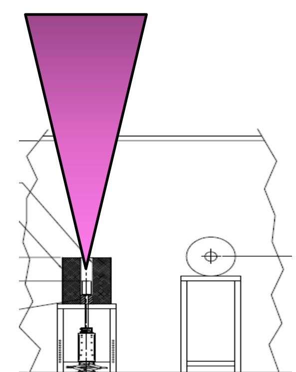
- Gamma imaging
- Debris removal and waste sorting
- Very sensitive stack gas monitoring for "approach to criticality" monitoring
- Exit contamination monitoring of vehicles
- Transportable laboratories
  - Radiochemistry
  - Measurement
  - Gamma in-vivo
  - Alpha in-vivo



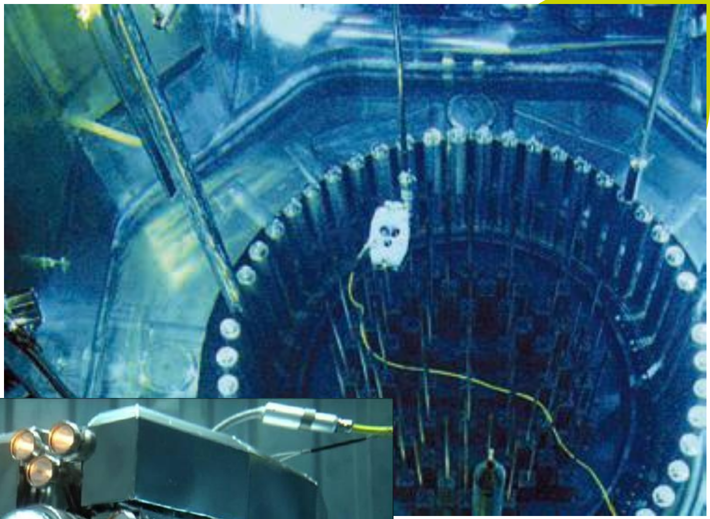


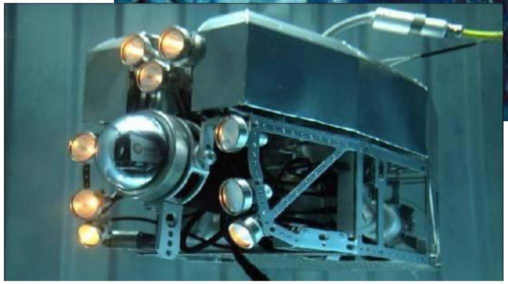




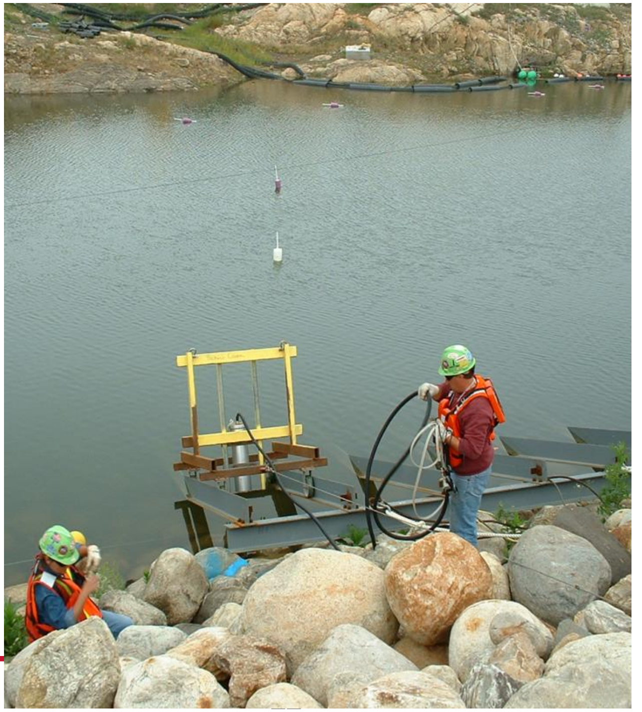


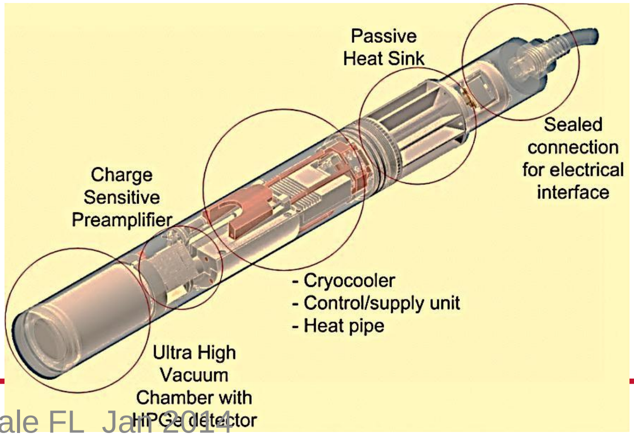
Underwater measurements





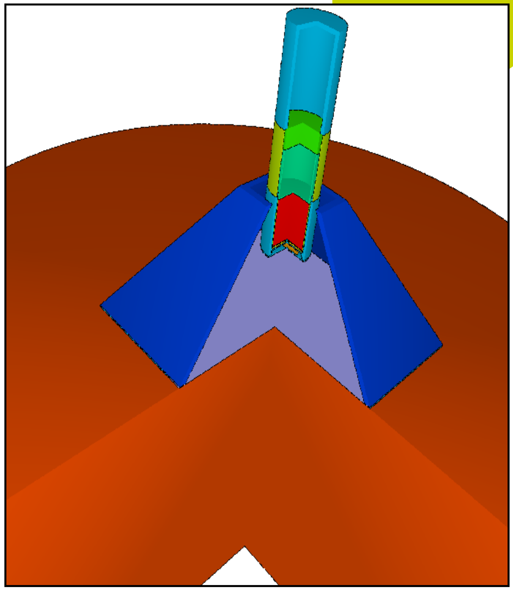
- ROV submarine initially proposed as part of fuel tank removal project
- Later there was need to know the inventory of radioactivity at the bottoms of rivers and lakes and seas [samples difficult and unreliable]
- Proposed several alternatives
  - LN cooled Ge – any size detector
    - Used many times before – Maine Yankee at right
  - Electrically cooled Ge
  - ROV submarine with LaBr scintillator
- Selected the ROV + LaBr option

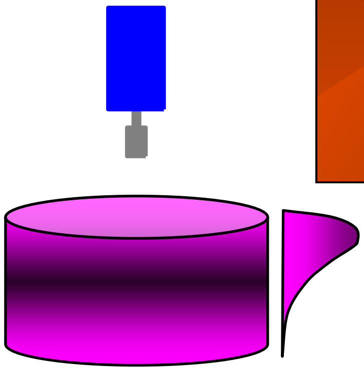


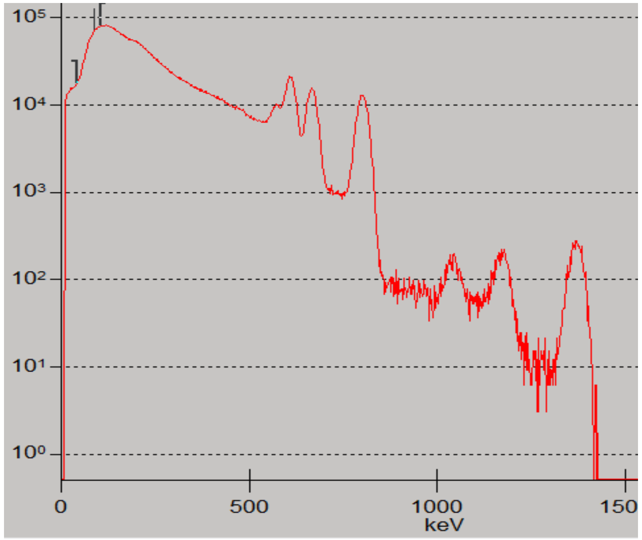


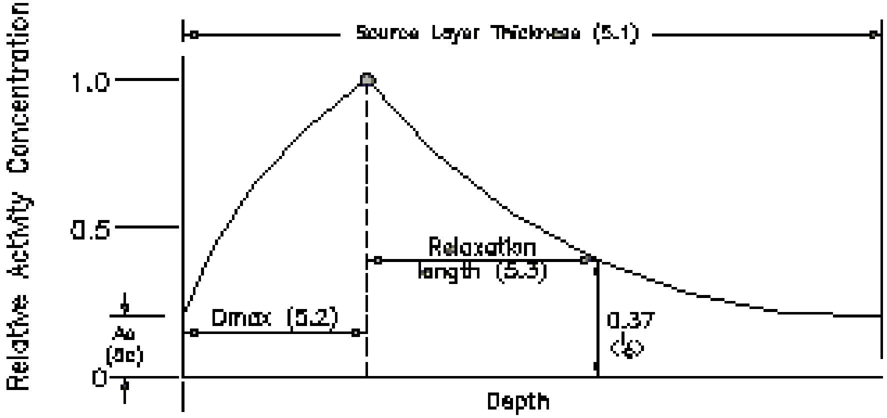
Shallow underwater measurements

- Large number of lakes and ponds [3700] to be measured
- Canals delivering water to rice fields – MANY
- Proposed water displacement tool around detector
- NaI detector to show that results are OK – 1min
- CeBr detector to estimate depth
  - LED stabilized; ISOCS Characterized
  - Using Cs134 low and high energy lines and ISOCS calculations to determine depth profile









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ALARA reminder

- **ALARA should apply to both real and imagined dose, and the economic consequences of imagined dose/activity. It is critically important to the success of the NPP industry**
- **Workers in NPP**
  - **41% will get cancer; 100% of their surviving spouses will blame the NPP**
  - **Most workers believe than an internal Rem is worse than an external Rem**
    - Unfortunately, having 40 DAC-hr/week limits in our regulations promote this mistaken belief
- **General population**
  - **Same two beliefs as above, but less opportunity to convince them otherwise**
  - **Contains children and infants who are more radiosensitive than adults**
    - Parents and grandparents are far more concerned about their dose, than their own
- **Japan**
  - **Same 4 beliefs as above, and a very radiophobic media we started ~70y ago**
  - **Live today with contamination in the environment and in the food**
    - Low, acceptable, but we are very good at measurements, and can find it
  - **Pure high quality food is very important in Japan**
    - Consumers are shunning food grown in the Fukushima area

Air contamination, respiratory protection

- Is radiation the biggest hazard here ? Not for me !
- The use of Respirators when not needed is not ALARA
- Cs very poor at internal dose, but good at external dose
- 2y of data showing that RP not needed outside buildings
- Proposed using many alarming a/b CAMs + confirmatory WBC to allow the 3000 workers on site to NOT use RP most of time

Food radiation limits

- Initial limits were low in Japan, and got even lower March 2012

Country	Water	Milk	Food	Baby food
European Union (note1)	1000	1000	1250	400
USA	1200	1200	1200	1200
Japan <Mar 2012	200	200	500	200
Japan >Mar 2012	10	200	100	50

  - **Units are Bq/kg of total radioactivity [Cs134+Cs137]**
  - **Note 1: The EU limits for food from Japan are the same as the Japan limits**
  - **K-40 comparison: milk, people, most vegetables ~50-100 Bq/kg**
- **If using detector other than Ge, then must show activity is less than half these limits**
- **Being interpreted as applicable to small items individually**
- **Difficult to economically measure these low levels**
- **Very important for local economy to show food is clean**
  - **"perfect" food is very important culturally in Japan**

Area around Fukushima very important for food production in Japan

- Fish
  - Fresh
  - Processed
- Spinach
- Wakame (seaweed)
- Rice

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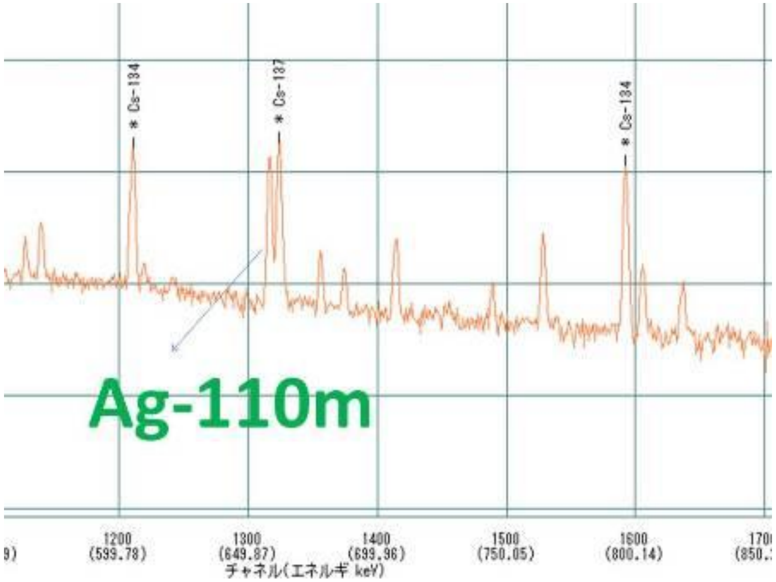
Spiders and Abalone are Little Silver Miners

- **Ag110m is present in soil, but very much lower than Cs134/137**
- **In spiders the Ag:Cs ratio is 1000x higher than in the surrounding soil**
  - **Cs-134 + Cs-137 = 3,656 Bq/kg live weight**
  - **Ag-110m = 1,397 Bq/kg live weight**
- **Bin Mori, University of Tokyo**
- **Which begs the questions:**
  - **What about radioactivity in their webs ? Or silk ?**
  - **Will there soon be a Japanese Spiderman ?**
- **Abalone**
  - **Cs 134+137 = 2,000 Bq/kg, 50x concentration from seawater**
  - **Ag-110m = 410 Bq/kg in meat and 1800 Bq/kg in liver**
  - **Very high preferential uptake of Ag over Cs**
- **Dietary advice**
  - **stay away from Abalone liver**
  - **only consume spiders in moderation**



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One of the roadside snacks we had in Cambodia last year

- **Crispy crunchy spicy deep-fried tarantulas; finger lickin' good**

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Many new radionuclide measurement systems now in Japan

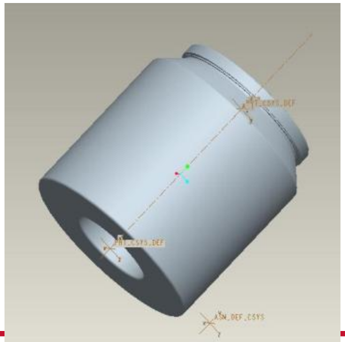
FoodScreen™
Radiological Food Screening System

Turn-key system for rapid screening of processed or raw food products for key nuclides of concern (^{131}I, ^{134}Cs and ^{137}Cs)

FoodSpec™
Radiological Food Analysis System

Turn-key system capable of identifying and quantifying virtually all nuclides found in a sample

- **About 700 sold by Canberra via Aloka**
  - **Perhaps 3-4x more by others**
- **New MB designed for new lower levels**



- **About 300 sold by Canberra**
  - **Perhaps 2x more by others**

Rice, and other food products

- Fukushima prefecture known for producing high quality rice
- Traditional statistical sampling regimes still allowed some rice above regulatory levels to escape the local embargo area
- Widely reported in press; consumers shunned rice from this area
- Prefecture decreed that 100% of the rice from there would be measured and certified to be clean
- QR sticker to get results
- 5 companies supplied ~150 systems [Canberra 30]
  - Designed, built and delivered in 6-8 months
  - Large NaI detector
  - Full gamma spectroscopy
  - 30 kg rice bags
  - MDA - 10Bq/kg in 10seconds, in 1uSv/hr background field

Rice warehouse with 4 counters

- **After each bag is counted, results are loaded into national database where consumer can view assay for that bag**
- **After first season of counting, expected 20,000 bags over limit but only found 71; too bad, no Ge systems.**
- **Units easily converted to assay boxes of apples, peaches, fish, …**

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Persimmons [gaki]

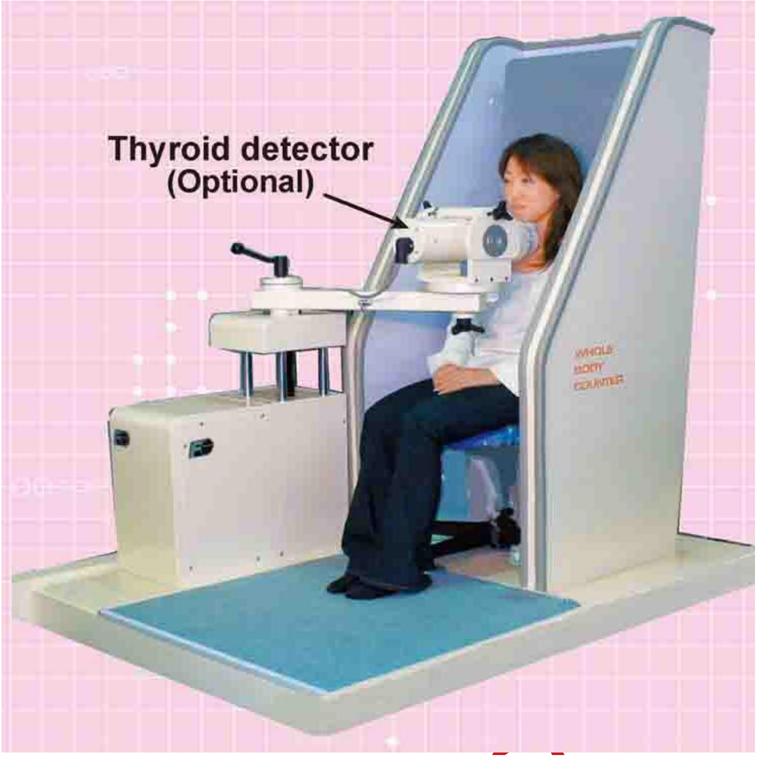
- Japanese persimmon when semi-dried and cured with sojou is very tasty and expensive – very good cash crop from the Fukushima region [Ampo-gaki]
- When fresh, Cs generally <100, OK; when dried commonly >100Bq/kg = bad
- But since expensive, people commonly only eat one – therefore rules interpreted to apply to single gaki = ~6 Bq each !!
- 6 Bq per fresh gaki is OK [<100Bq/kg]
  6 Bq per dried gaki is Bad !! [>100Bq/kg]
- Need better definition in regulations - US too

The worlds only automatic persimmon counter

- 12 units installed
  - finished 2 weeks ago
- 32 NaI 3x4x2" detectors and MCAs
- Typical count time ~1 minute per 8 items

Internal doses of workers

- **4 In-vivo counters at Dai-ichi; 4 more at Dai-ni before accident**
- **WBCs in Japan NPPs all local brands that qualify to local standards**
  - **All chair-types**
  - **All with incomplete shielding [side, back, not front]**
  - **Most are plastic non-spectroscopic gross counters**
  - **Maybe OK for normal plant operations**
    - Where internal dose is minimal
    - And if located in areas where background is low
    - *And where there are not many lawyers*
  - **Not suitable for these type events**
    - TMI, Chernobyl, Fukushima
- **All WBCs at F1 & F2 unusable**
  - **Initially because of power**
  - **After power restored, because of high background, or water damage**



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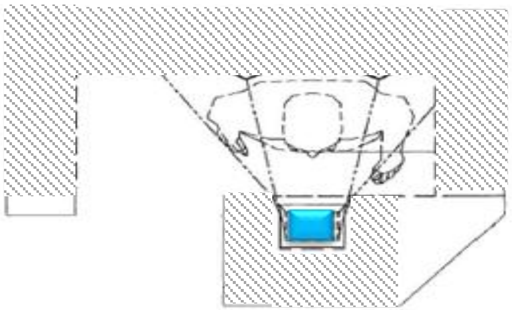
Worker internal exposures by JAEA

- Most common WBC in rest of world NPPs is Canberra FastScan
  - Full gamma spectroscopy
  - Total body measurement
  - Full shadow-shield for use in elevated external background



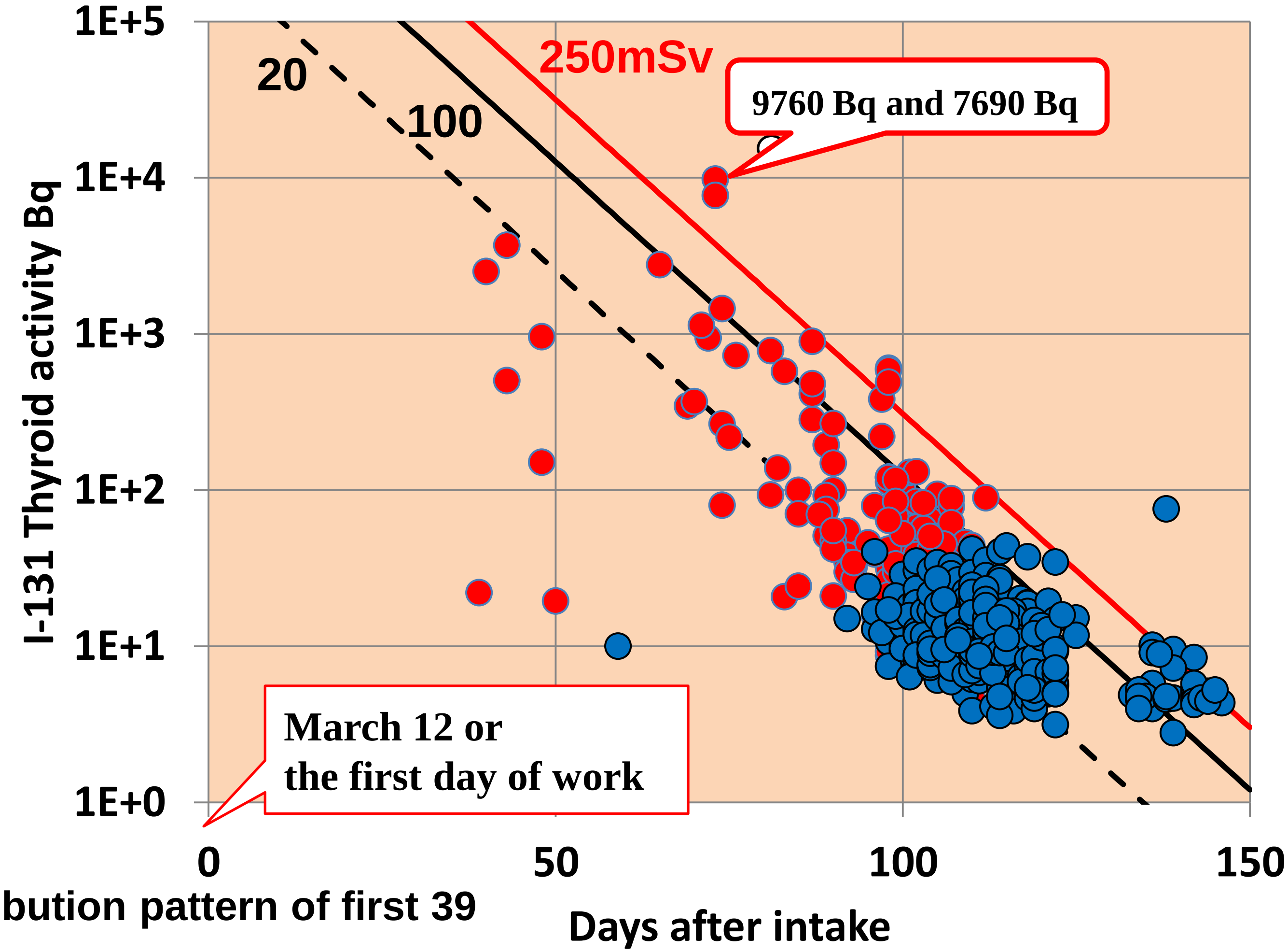
- None in Japan NPPs
- 4 FastScans at JAEA, including 2 mobile units
- JAEA mobile FastScan WBC moved to Onahama plant [55km S] and started counting selected workers on March 23 [+2w].
- Used to select workers for follow-up measurements

Worker internal exposures at JAEA-Tokai

- 23 April [+6weeks] - 5 August 2011
- Workers with preliminary dose estimate >20 mSv went to JAEA Tokai for additional monitoring.
- Whole body monitoring
  - 2x Ge detectors in 4pi shielded room with 20 cm thickness iron
  - 2x Canberra FastScan w/dual NaI detectors
- Earthquake reduced elevation of shield 1m and caused minor damage to mechanicals
- Thyroid monitoring
  - Ge detectors in the shielding room
  - Later NaI detectors on neck
- Number of measured workers
  - 39 in initial wave [those >20mSv]
  - 560 total [6 female]

Thyroid I-131 results [caused most of internal dose]

- Straight lines correspond to CEDE of 20, 100, and 250 mSv
- Acute intake elemental iodine assumed
- Intake on March 12 or first day of work
- Red is first 39 workers
  - Est >20mSv
- Blue is next group for 560 total workers
  - Most are also >20mSv too
  - Similar dose distribution pattern of first 39 workers
  - Don't know how first 39 were selected



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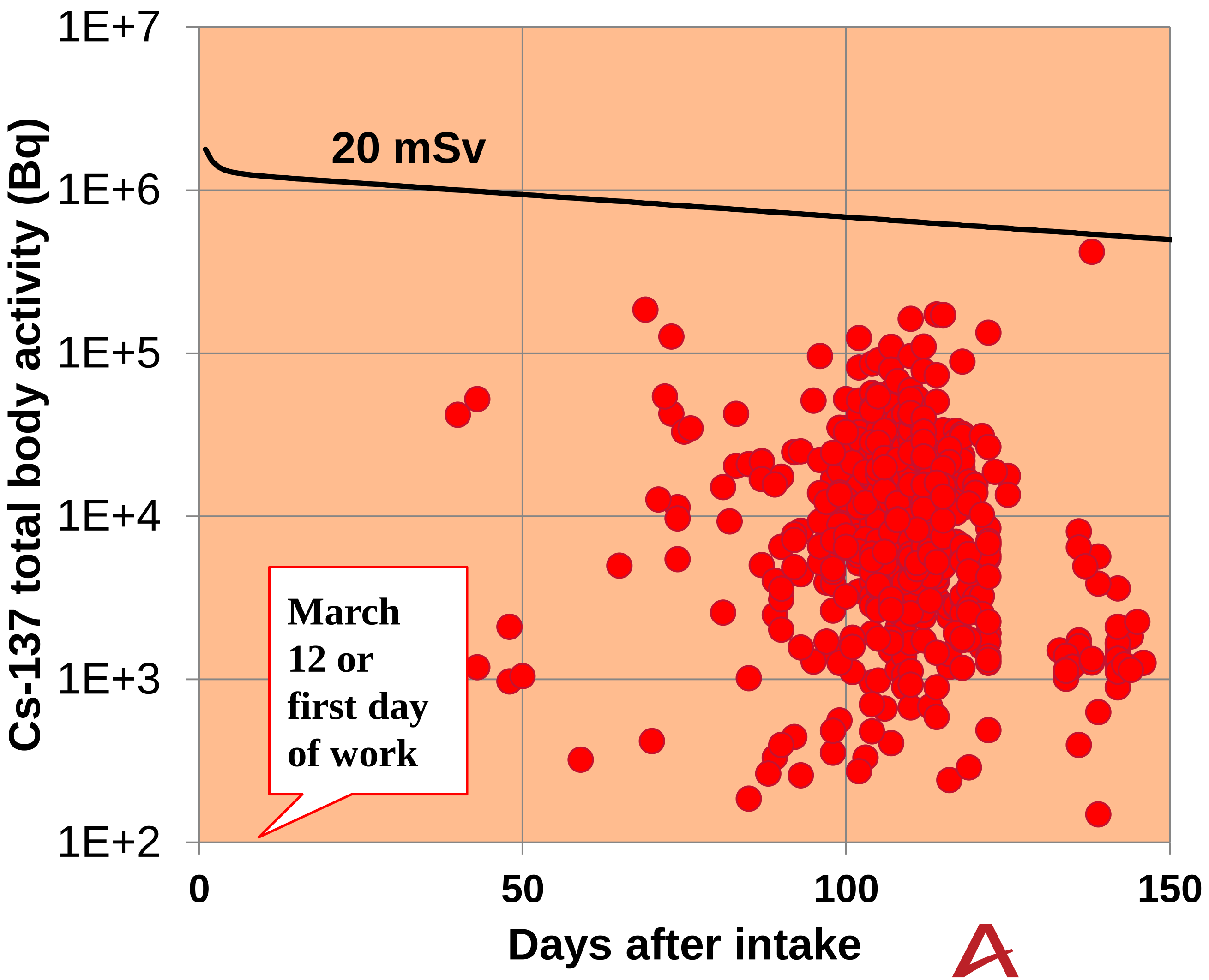
Cs-137 results

- Straight lines correspond to CEDE of 20 mSv
- Acute intake of type F compounds with 5um AMAD assumed
- Intake on March 12 or first day of work
- All 560 workers; no difference between first 39



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J-Village WBC station implemented by TEPCO

- **Built two large temporary structures**
- **Installed Tungsten blankets to reduce background**
- **One facility for 10 plastic chair-type WBCs**
  - **Additional shielding**

- **Other facility for 1 mobile and 1 fixed FastScan**
  - **Shielding not necessary, but done for consistency**
  - **Used for all workers >screening level on plastic WBCs**
  - **Now only for “special” ocassions.**

External contamination monitoring

- End of 2011 situation
  - 20uSv/hr field
  - multiple people waiting in line
  - hand-frisker surveys
- Not ALARA
- Inadequate survey method
  – should be 2-3 min per INPO – in normal background
- Expensive in lost productive labor
- Asked by TEPCO for alternative solution

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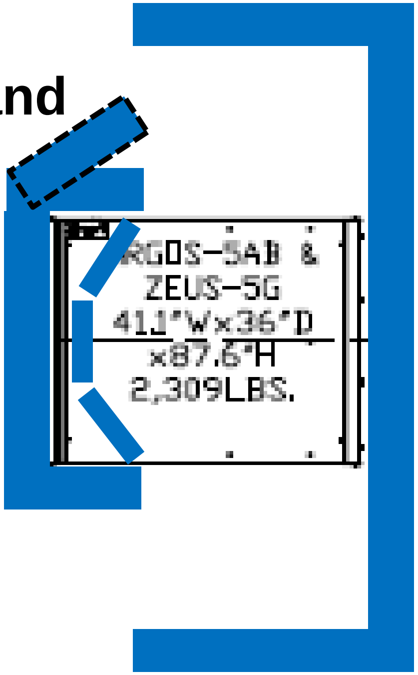
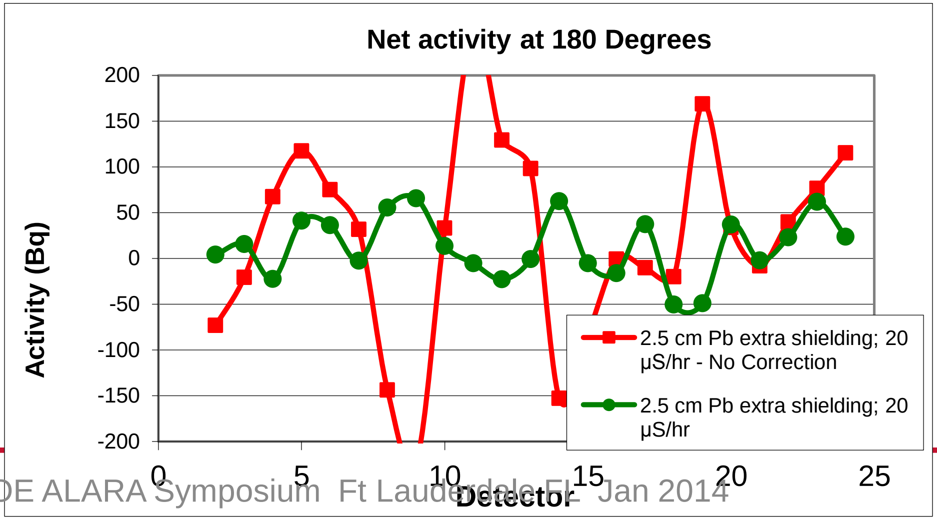
Worker external contamination

- **Requirements:**
  - **4 Bq/cm2 in 10x10cm area [400 Bq] in a 20 uSv/hr**
- **Performance of Argos**
  - **1 Bq/cm2 in 10x10cm area [100 Bq] in 0.03 uSv/hr**
- **Problems cannot be solved by longer count time because of the person changes the background**
- **Extra shielding not adequate due to scatter**
- **But OK with combination of additional shielding and subject-size detector-specific correction factors**
  - **E.g. implementing AccuCount feature on beta detectors**





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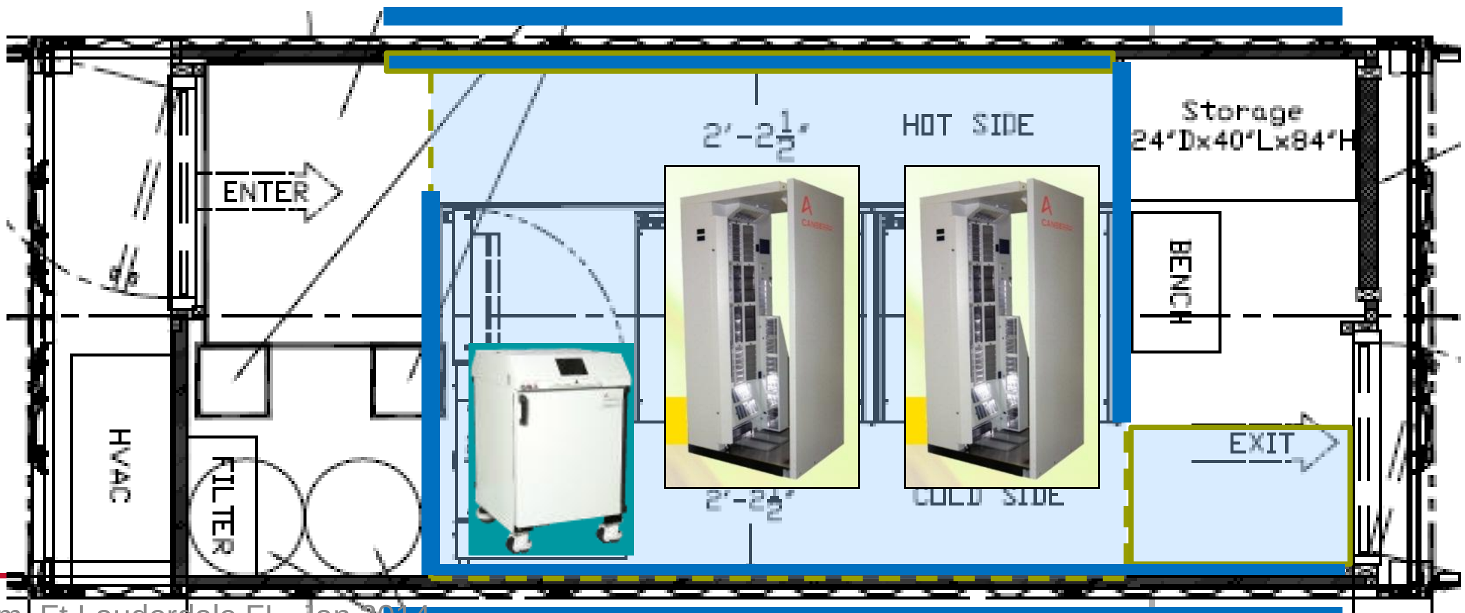
Shielded Contamination Control Container

- 20’ ISO container with 2 Argos;
- Fully assembled and tested at factory; only needs electricity to run
- Can be moved around on site project progresses
- 5cm of Steel can be built into unit walls and floor
- Additional steel can be added to wall[s] and roof on site if needed
- Contains 2 Argos units with Zeus option and Cronos object counter
- No order; person wanted it moved to new job



In-Vivo counting other accidents

- TMI accident and cleanup
  - 1 mobile pre-Accuscan during accident for workers
    - Very comforting to Techs that took initial RCS sample
  - 1 mobile Helgeson bed unit for population
  - 1 FastScan and 1 Accuscan in modular building for cleanup and unit 2 operations
- Chernobyl
  - 7 mobile FastScans [6 part of German population counting project]
  - 1 Accuscan-II, 1 U/Pu Lung counter for cleanup

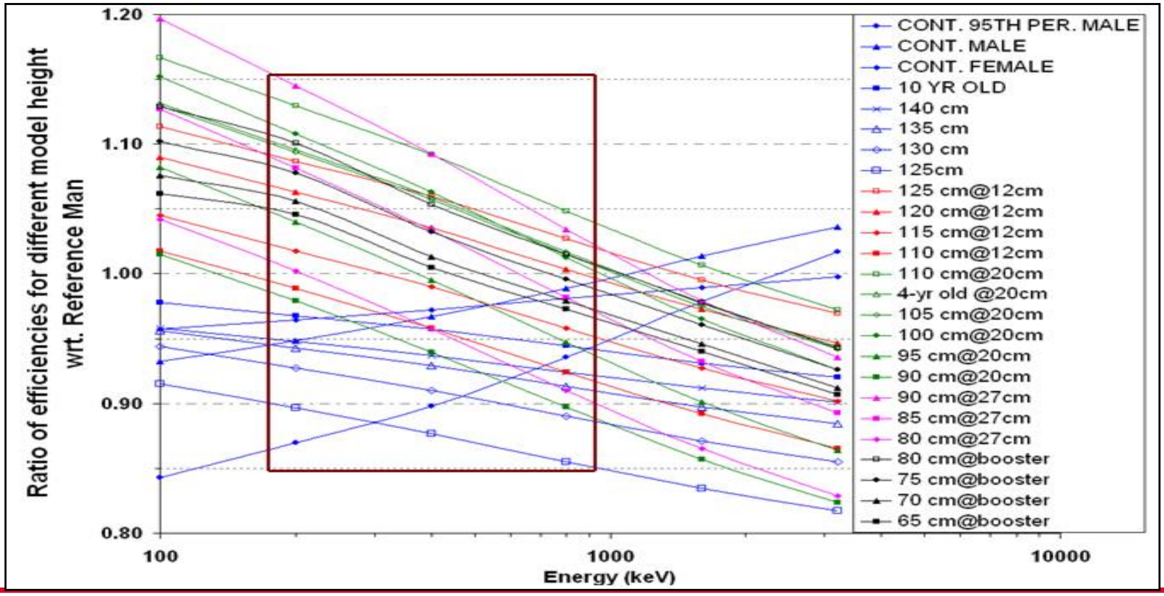
InVivo counting in Japan

- **10 Canberra Chair-types in ‘80s, probably in response to TMI**
- **Modern WBCs in Japan, before the Fukushima accident**
  - **1 Accuscan;   Scanning NaI Bed**
  - **1 Accuscan-II; Scanning Ge**
  - **6 FastScans; 2 mobile**
  - **3 U/Pu Lung counters**
  - **None at NPPs**

- **After accident**
  - **US Military – 60,000 affected workers**
    - 3 FastScans and one Accuscan-II quickly installed at military bases
  - **TEPCO at J Village**
    - 1 new FastScan, 1 mobile from JAEA
  - **Fukushima Prefecture and other locations ~ 1y later**
    - ~60 FastScans
    - ~20 of them Mobile
    - “defacto” standard for population measurements

Population in-vivo counting - children

- WBCs designed for radiation workers – adults
- Fastscan has constant efficiency for 99th percentile males [75”] to 1st percentile females [57”]
- Used prototype version of ISOCS software to simulate child-size BOMAB phantoms.
- If short people stand on platform, results within 15% for all subject sizes when using a single adult BOMAB calibration



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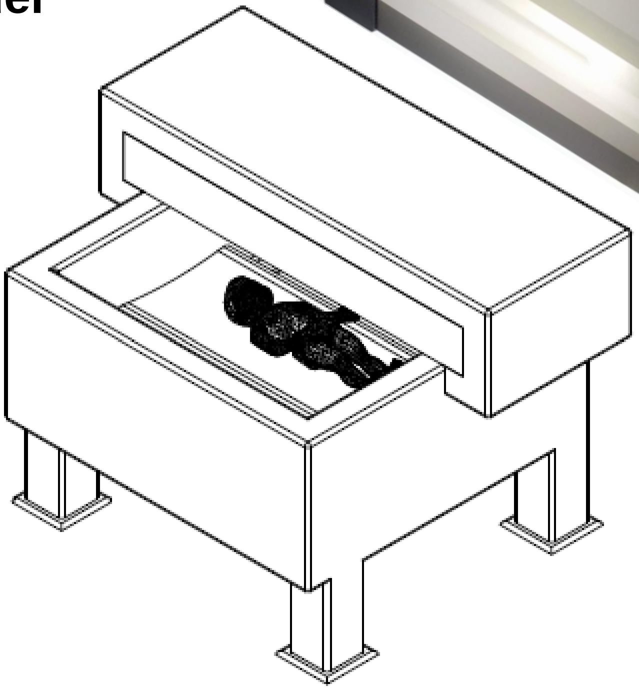
Population in-vivo counting - babies

- Babies are very important to their parents
- Babies have less mass than adults, less Cs134-137 and less K40
- Population counts criticized; didn't detect K-40 therefore Cs results suspect
- Design similar to horizontal FastScan; 4 large detectors
- Need shielding above counter to reduce background
  - Cs 134/7 on roofs; K40 in building walls and ceiling
- Opening allows parent to see and touch child
- One installed few weeks ago; 2 more on order



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NHK TV coverage
4-min movie, hope it works

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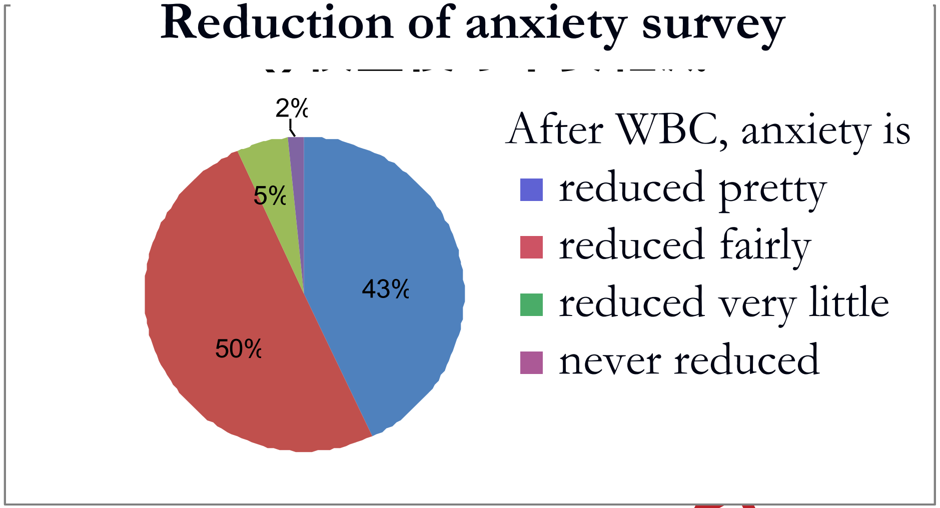
WBC of residents by JAEA at Tokai

- Asked by Fukushima prefecture
- 3000 July, Aug 2011
- 4000 Sep - Jan 2012
- 20,000 total - present
- 2 FastScans + Chair WBC
  - 100 per day average
- Process:
  - Registration
  - Explanation of process
  - Surface contamination check
  - WBC
  - Dose calculation
  - Explanation of results !!

Communication

The result was explained to a residents by JAEA expert in a manner of interview or phone consultation.

Many residents replied that WBC and consultation is effective for reduction of anxiety on radiological health effect.



THINGS WE CAN DO BETTER

Full set, not just ALARA-related

Things we can do better 1/3

- **Environmental monitoring stations that are better for accidents**
  - All 3 Rx accidents had most releases from un-monitored points
  - Autonomous power for operation and data communication
  - Iodine collection – even better if active measurement
  - Air mover is a challenge – currently high power devices; maybe lower power lower sensitivity w/o power is OK
- **Iodine Thyroid measurement capability for large scale rapid deployment, easy for "untrained" operator**
  - Short T½ nuclides to not cause problems
  - Procedures to do good measurements in elevated background areas
- **Portable laboratories to take near to accident site**
  - Radiochemistry, radiation measurement, in-vivo, contamination
- **Rapid response to public fears – reduce public anxiety**
  - Measure and report: in-vivo adults and babies, pets, other treasured items
  - Far earlier than done here

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Things we can do better 2/3

- Accepted values on re-occupation of evacuation zone
  - Inform users of age-specific risk, as compared to others that they accept
  - Inform users how to minimize their radiation dose
  - Give them tools to minimize, and feel better – recording personnel dosimeter, area doserate meter, food counter, routine in-vivo counts and health checks
- Make rad instruments easy for “untrained” people to use
  - Contamination monitors rather than hand-frisking
  - Concept of stable background unrealistic
  - Background is elevated, variable in time, variable in space
- Reactor instrumentation that can survive accidents and reliable give the status of the core
  - Multiple instruments, independent, alternate power sources
- Gamma cameras that are practical
  - Light weight; wide dynamic range [or low and high models]; no off-axis false response
- Internationally accepted and common standards for radioactivity in food and on export/import of products

Things we can do better 3/3

- Need training process for large number of non-technical radiation measurements done by general public
  - E.g. YouTube videos on how to use, how to survey, how to check cal, …
- Better portable spectroscopy instruments
  - More smart and automatic
  - Easily configurable [automatic?] for “normal” and “accident” conditions
  - This may be a good area for these new high res’n scint detectors
- Reality check about all these instrumentation improvements:
  - Accidents don’t drive commercial companies to make new instruments
  - Instruments ONLY for accident use won’t be useful during accidents; best to design instruments for routine use that can also be used in accidents
- Minimize evacuations
  - ~600 people died from the trauma of the evacuation
  - Make KI available earlier to workers and population

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My take-home message

- **ALARA is not just Dose-Optimization for Radiation Workers for regulatory purposes**

- **ALARA thinking and Emergency planning should include**
  - **Radiation workers thoughts and beliefs about their level of radiation protection**
  - **Non-radiation workers**
    - **At the plant**
    - **General population around the plant**

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THANK YOU!
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STOP