IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Enhancing Nuclear Safety

Fukushima Worker Dose Assessment: Lessons Learnt

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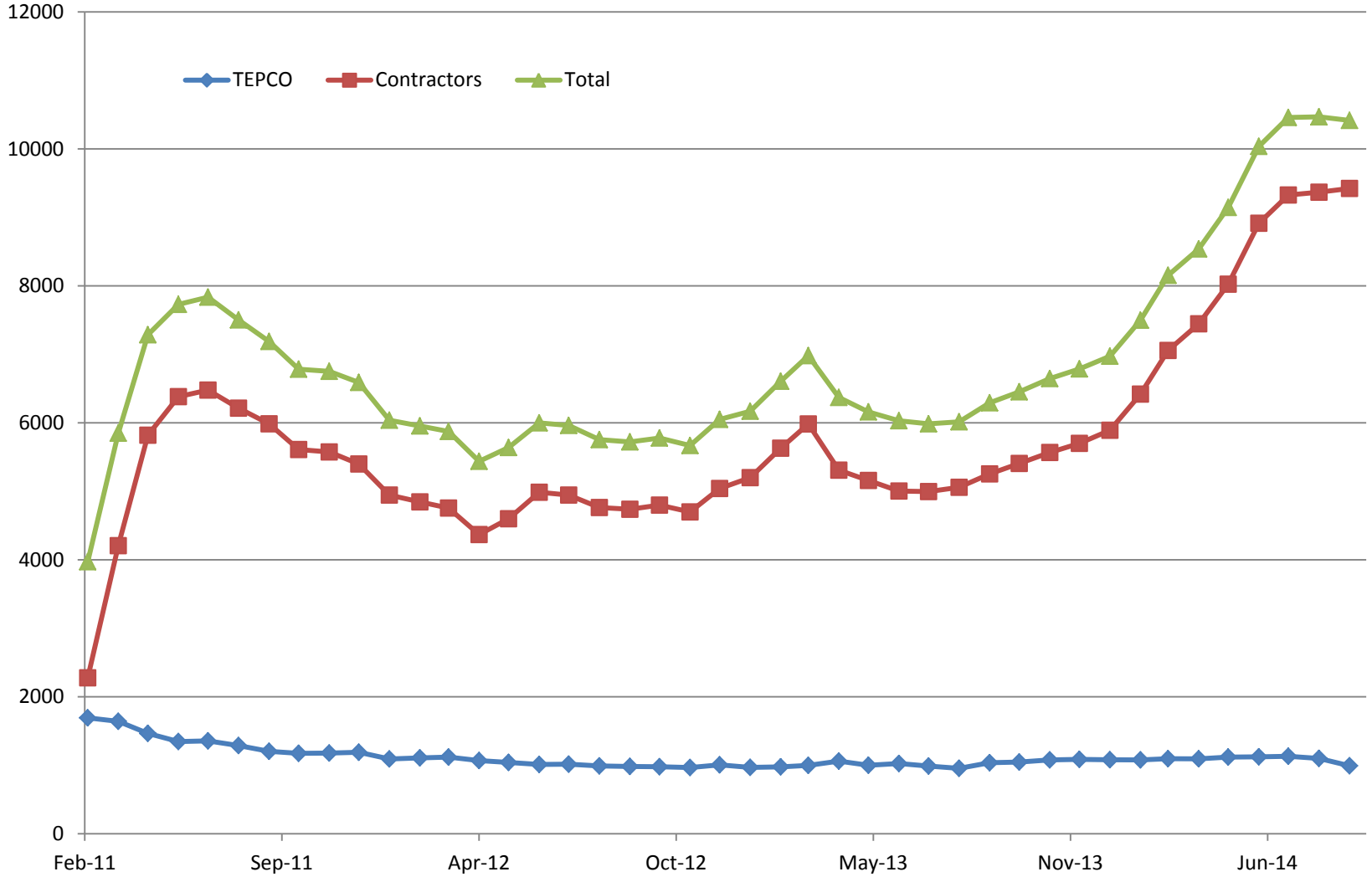
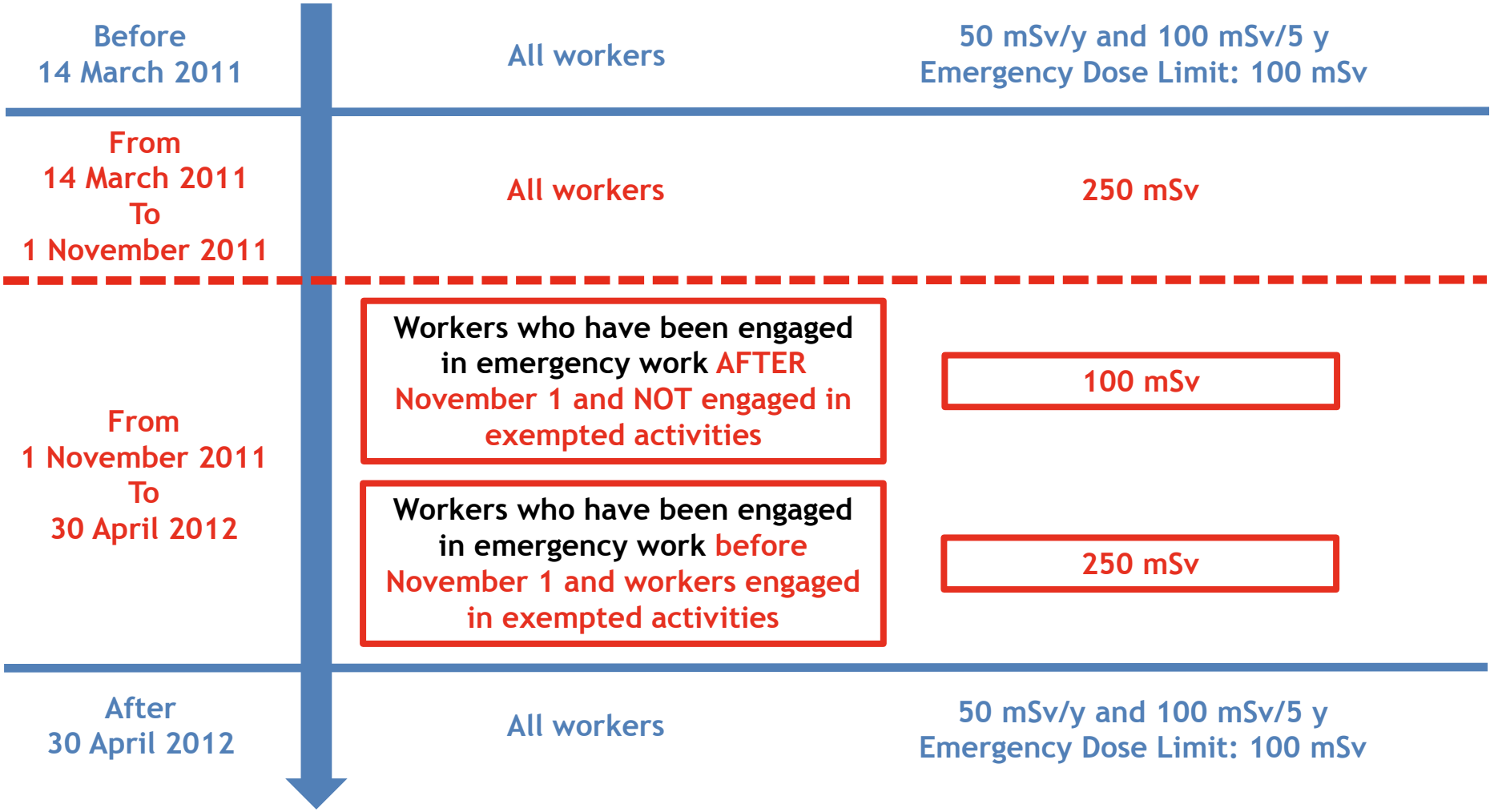
Art.31 Scientific Seminar
18 November 2014

**Some slides prepared for a 2014-IRPA presentation (co-cuthors: G Etherington, JR Jourdain, W Zhang, J Harrison) have been adapted for this presentation*

Evolution of engaged workers' statistics month by month (as of 30 September 2014)



Exposure Dose Limits for Workers



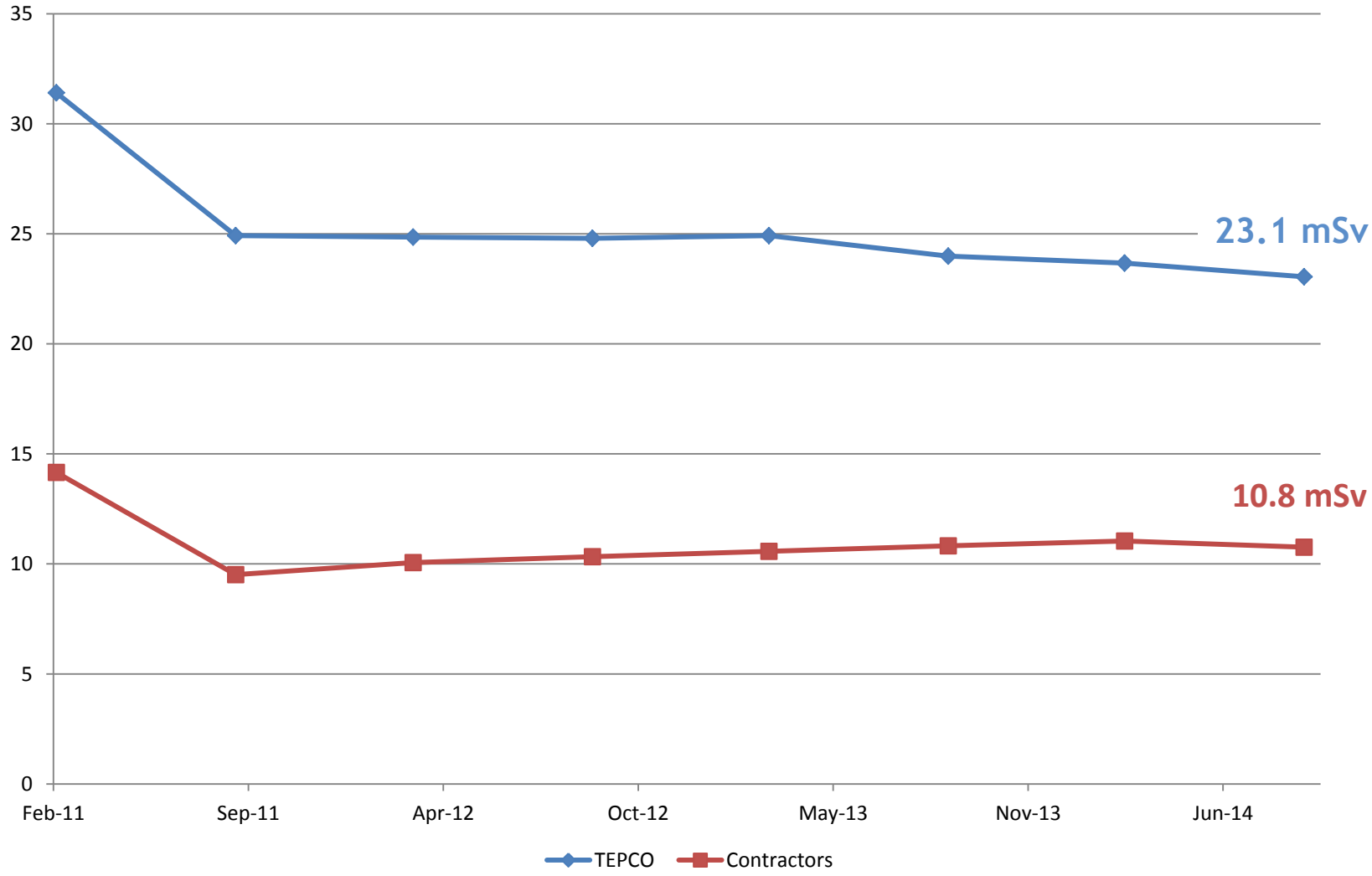
Exempted activities: to maintain functions for cooling reactor systems & spent fuel storage pools, and functions for suppressing the release of radioactive materials

Worker dose distribution from March 2011 to September 2014

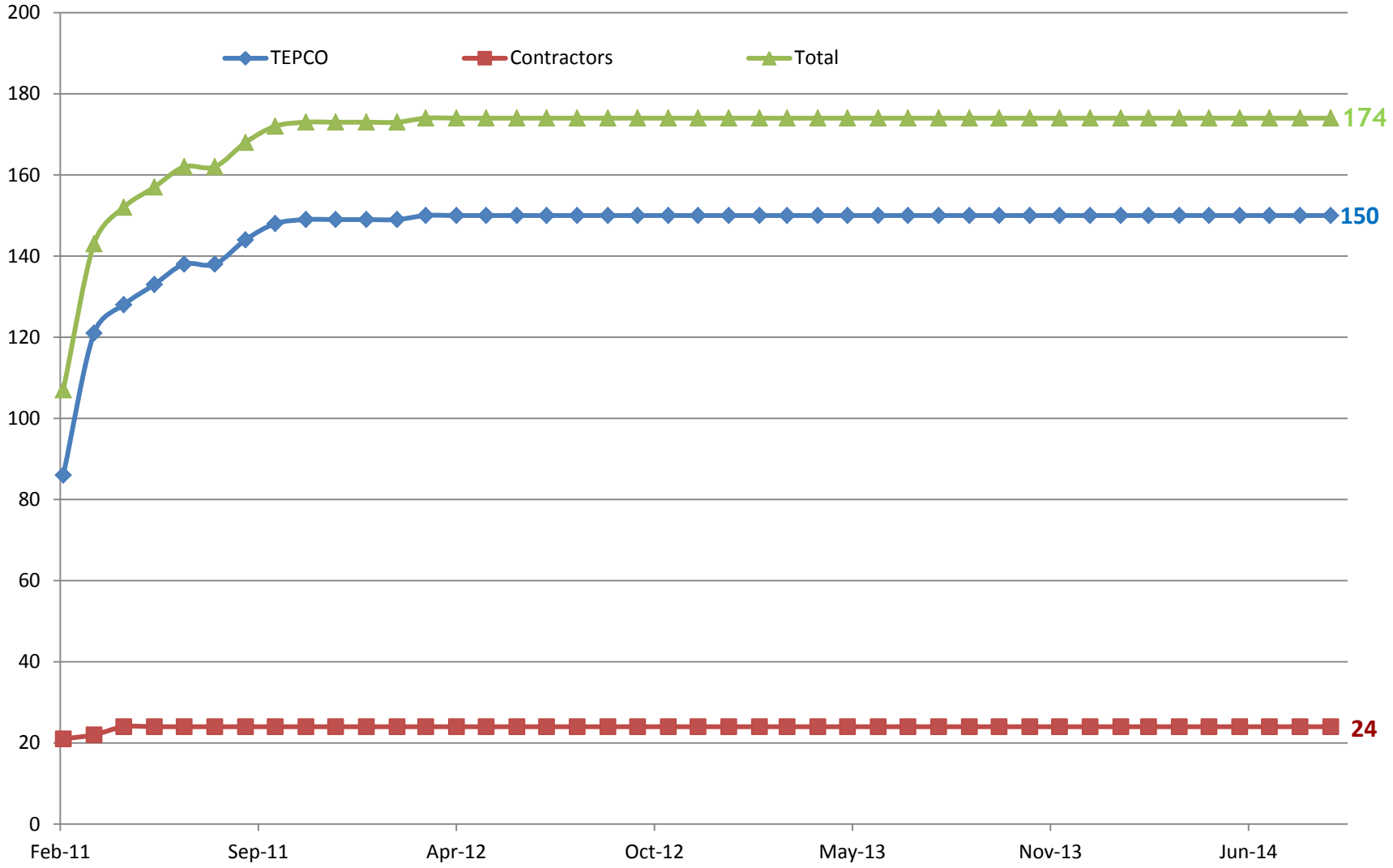
Cumulative dose	TEPCO	Contractors	Total
> 250 mSv	6	0	6
200 – 250 mSv	1	2	3
150 – 200 mSv	25	2	27
100 – 150 mSv	118	20	138
75 – 100 mSv	281	163	444
50 – 75 mSv	320	1 133	1 453
20 – 50 mSv	620	5 035	5 655
10 – 20 mSv	566	4 652	5 218
5 – 10 mSv	476	4 462	4 938
1 – 5 mSv	760	8 275	9 035
< 1 mSv	1 160	10 377	11 537
Total	4 333	34 121	38 454
Maximum (mSv)	678.80	238.42	-
Average (mSv)	23.05	10.76	12.15

From TEPCO Press Release, Oct 31, 2014 - http://www.tepco.co.jp/en/press/corp-com/release/2014/1243935_5892.html

Evolution of average cumulative dose received



Evolution of total workers above 100 mSv



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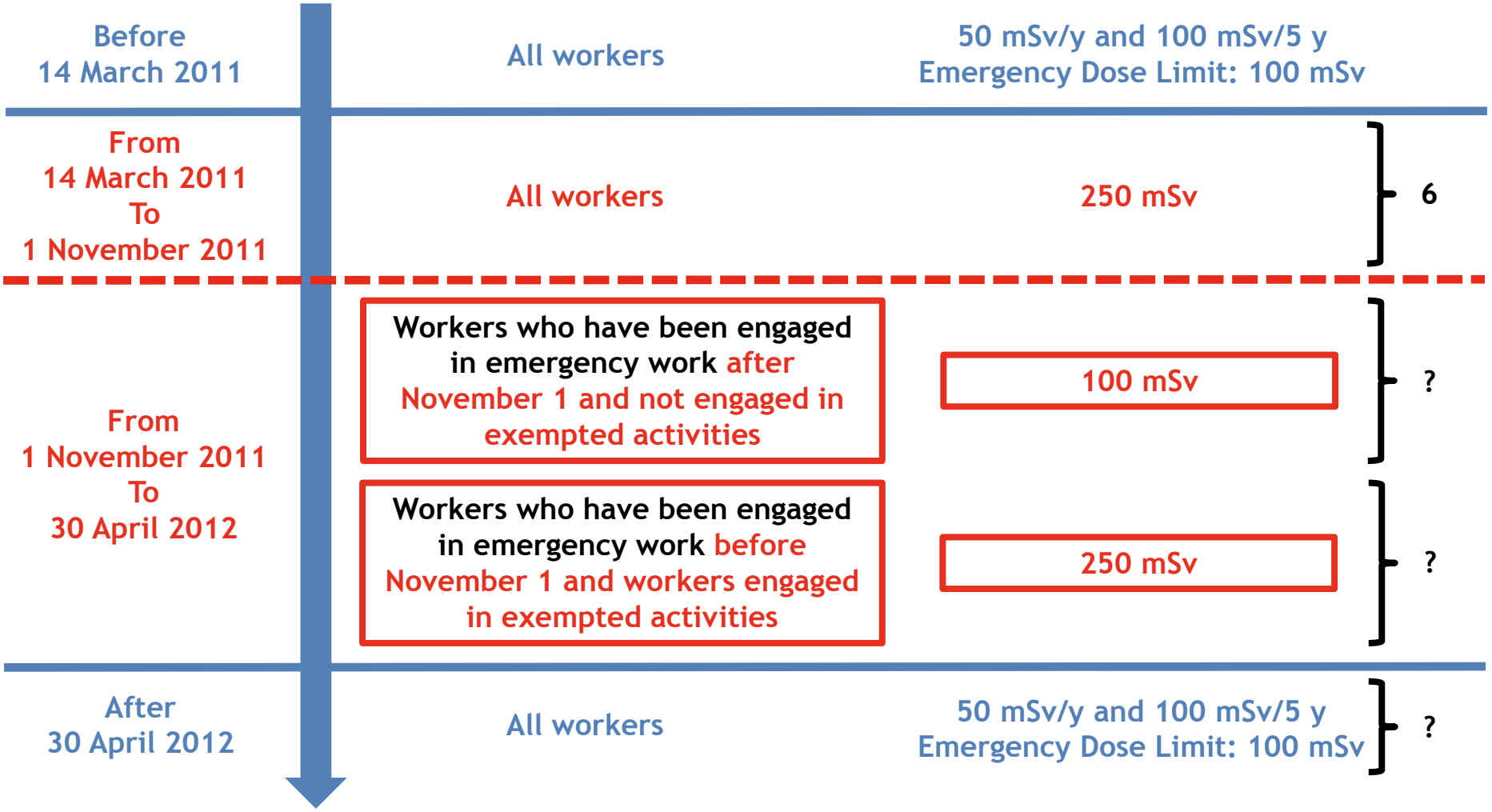
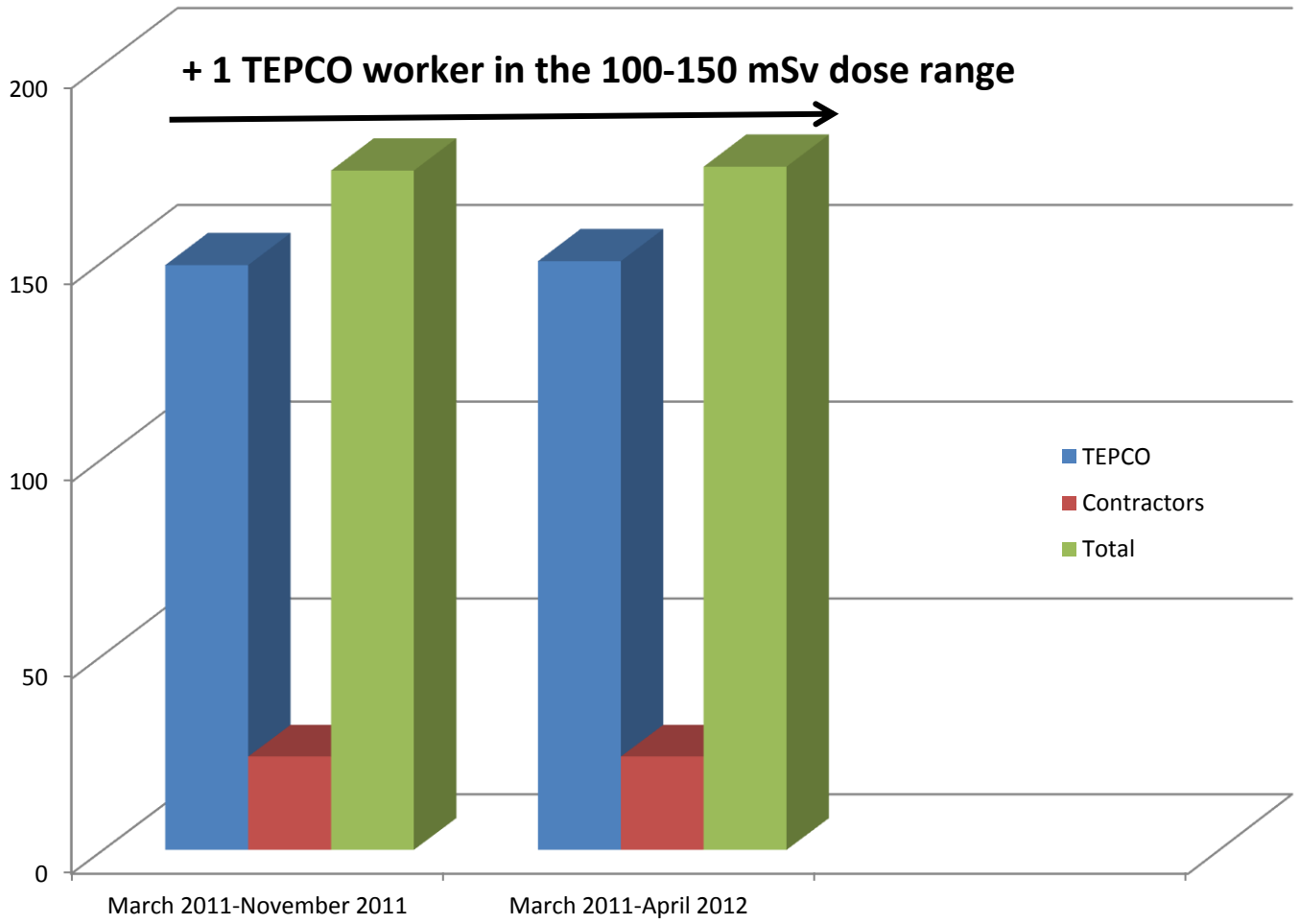
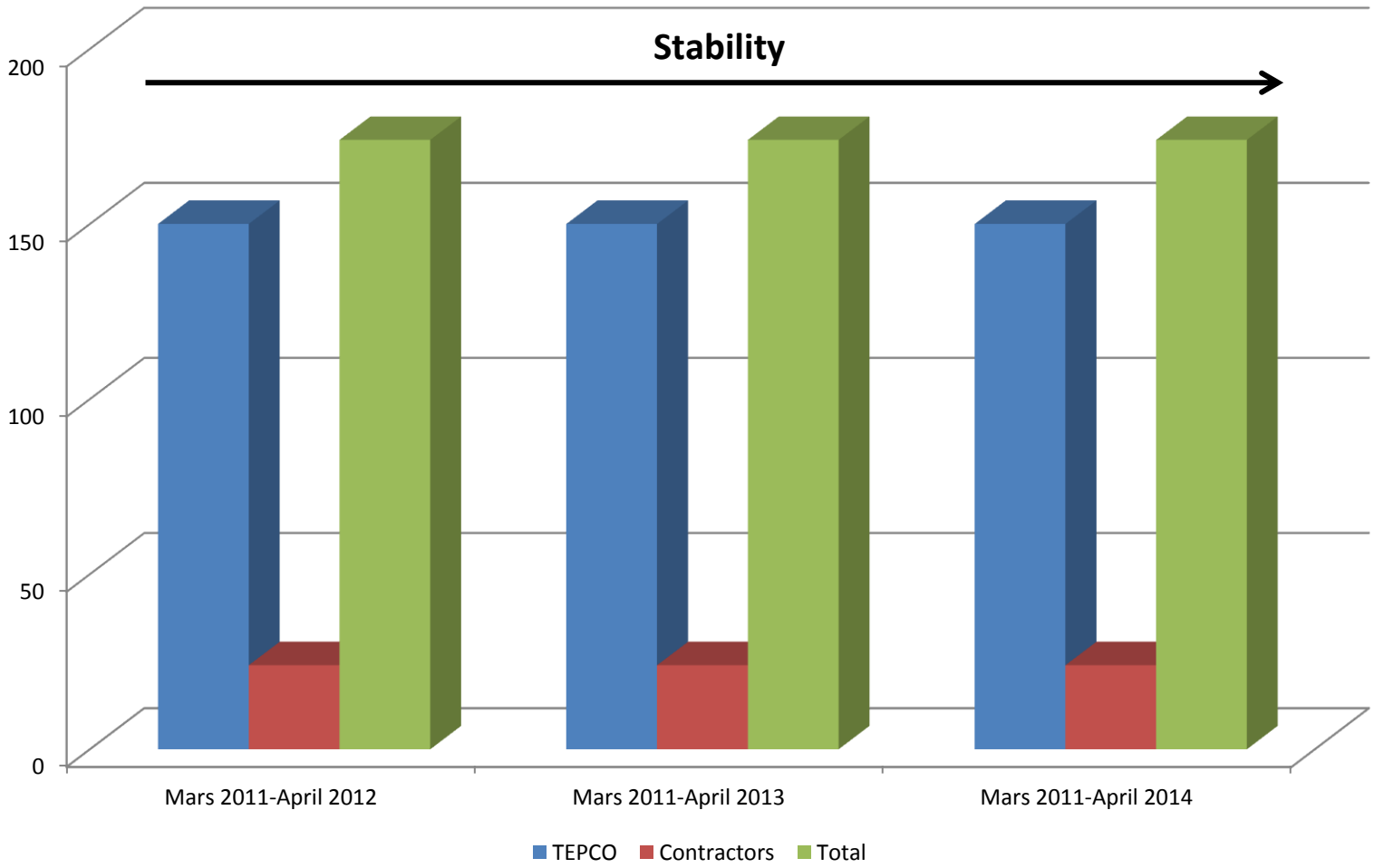


Exempted activities: to maintain functions for cooling reactor systems & spent fuel storage pools, and functions for suppressing the release of radioactive materials

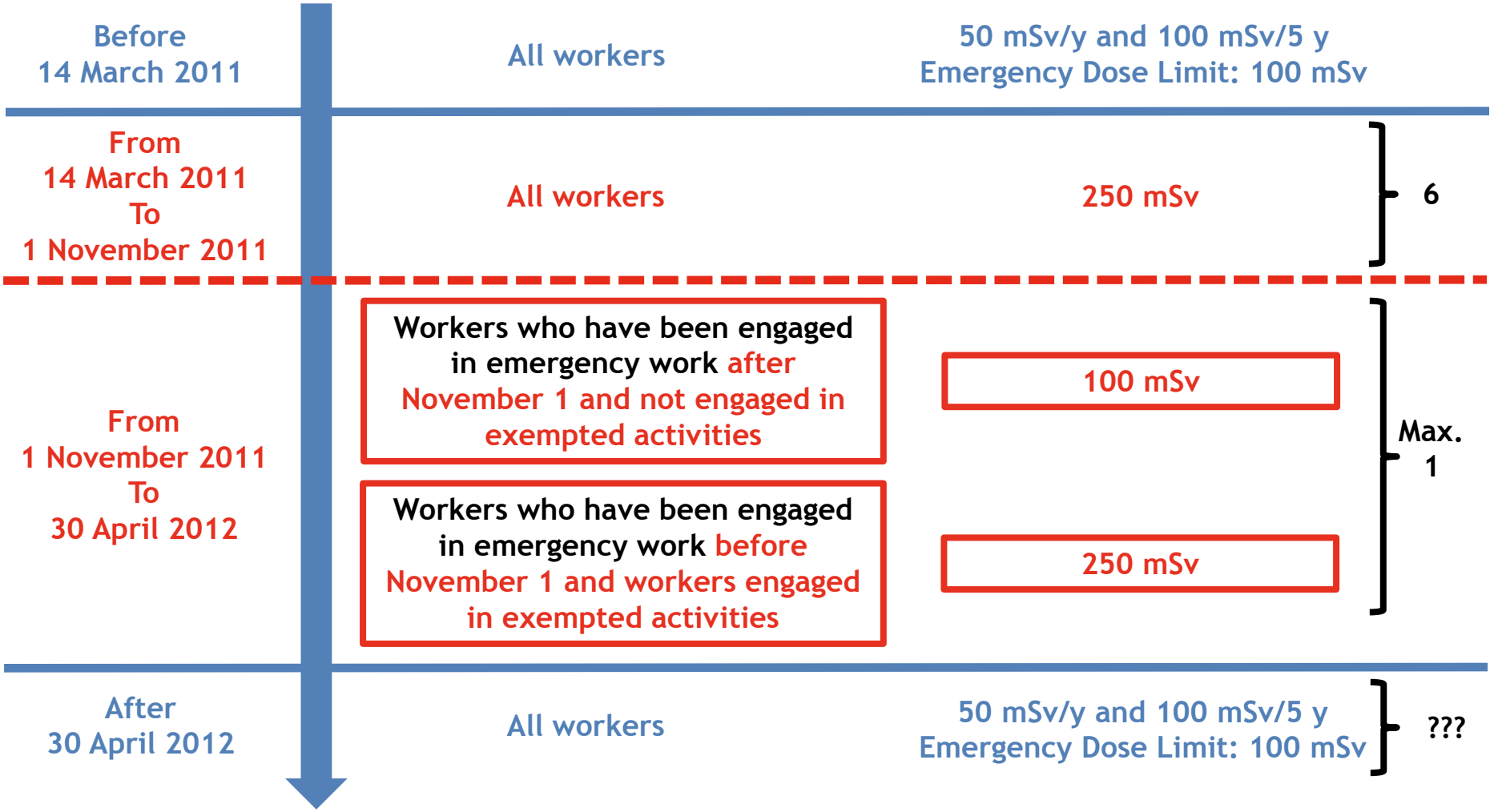
Evolution of workers >100 mSv (before Apr. 2012)



Evolution of workers >100 mSv (after Apr. 2012)



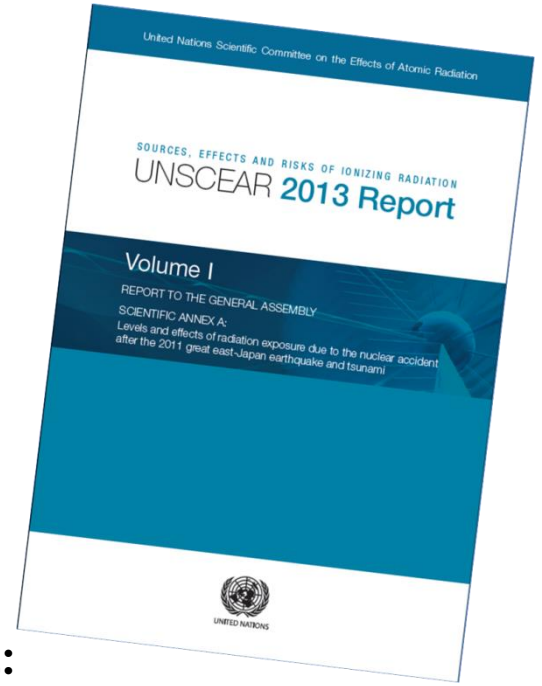
Exposure Dose Limits for Workers



The tables provided in TEPCO's press releases cannot be used to estimate workers who received doses above the exposure dose limit after 30 April 2012. Individual data are needed.

The UNSCEAR assessment

Aim: to provide the UN General Assembly with an assessment of the levels of exposure and radiation risks due to the Fukushima nuclear accident



Report:
http://www.unscear.org/unscear/en/publications/2013_1.html

UNSCEAR Committee

UNSCEAR Secretariat

- **Data, quality assurance**
- **Radionuclide releases, dispersion, deposition**
- **Pathways, public doses, non-human biota**
- **Workers doses**
- **Health implications**

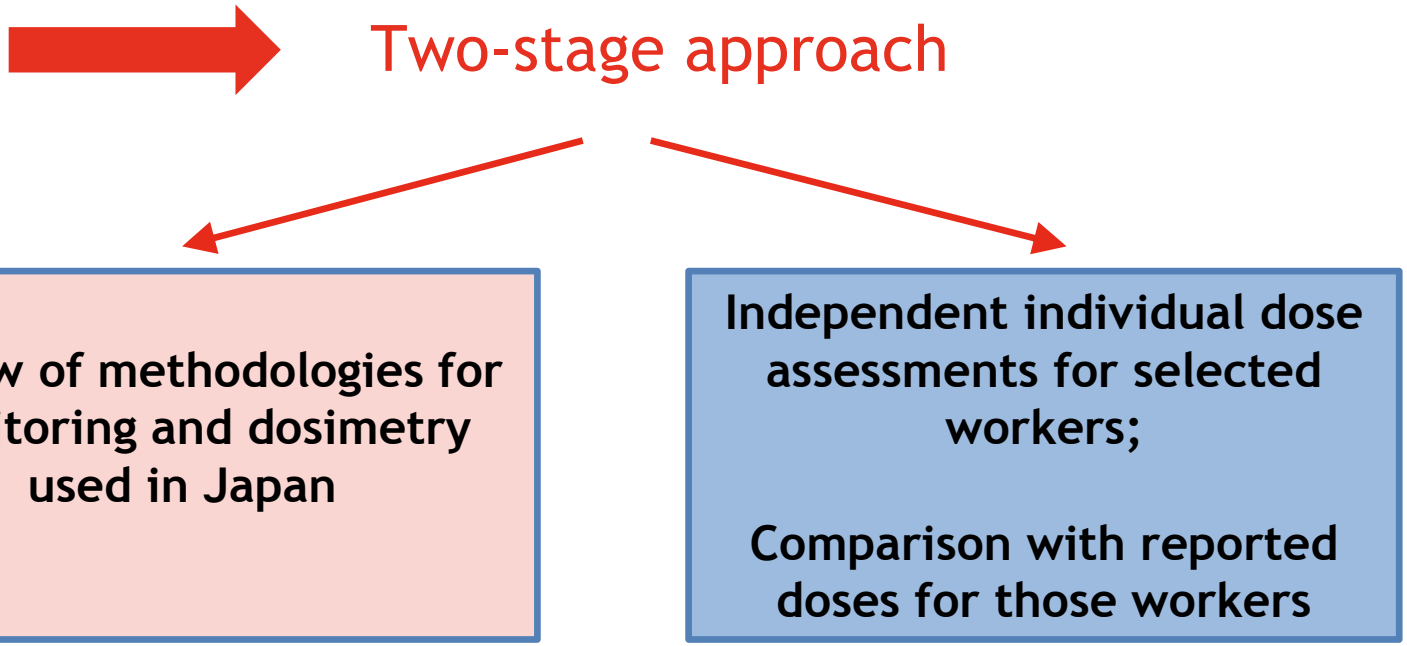
The worker UNSCEAR assessment

Scope: workers who were involved in the emergency response and clean-up operations before 31 October 2012

- Review of reported effective doses and absorbed doses to organs
- Assessment of the reliability of reported doses (using information on exposures provided from Japan)
- Projected risks to health
- Observed health effects

Assessment of the reliability of reported doses

Re-assessment or review of ~ 25 000 individual worker dose assessments would not have been possible. Therefore:



Review of methods: external dosimetry

"Instrumentation, technical standards and calibration methods used appear to meet generally-accepted requirements for individual monitoring"

Most significant issue: use of shared dosemeters

"In the absence of information on the extent to which the conditions described (below) were met for individual workers, some reservations remained about the reliability of the external dosimetry performed before 1 April 2011"

TEPCO conditions:

- Dose for the task was less than 10 mSv
- The workplace environmental dose rate was known
- Variations in dose rate with location at the site of the task to be performed were not large
- Members of an operational group were always together at the work site

Review of methods: internal contamination monitoring & dosimetry

"The measurement systems, calibration phantoms and methods, and quality control procedures were adequate for conducting in vivo measurements during a radiation emergency"

"Software (was) appropriate for assessing intakes,… committed effective doses and absorbed doses"

Most significant issue:

Delay in commencing reliable *in vivo* measurements of ^{131}I in the thyroid:

- mid-April 2011 – for some workers
- mid- to late-May 2011 - for most workers

Delay in starting ^{131}I in thyroid measurements - I

➔ ^{131}I was not measurable in the thyroid of many workers.

Two estimation methods were used:

"Environmental ratio" method

- Environmental measurements of time-dependent ^{131}I:^{137}Cs ratio were used
- ^{131}I intake estimated from ^{137}Cs intake determined from a whole-body measurement

"*… judged that estimates derived using this method had very large uncertainties*"

"Minimum Detectable Activity" (MDA) method

- ^{131}I in thyroid assumed equal to MDA

"*… judged to provide a reliable estimate of the upper limit on ^{131}I intake, but could not be taken to provide a reliable estimate of the true intake*"

Delay in starting ^{131}I in thyroid measurements - II

➔ Shorter-lived radionuclides (^{132}Te, ^{132}I, ^{133}I, ^{136}Cs) would have been undetectable in the body at the time of measurement.

Assessment of potential additional contributions to internal dose

(a) Workers at FDNPS during the period 12–19 March 2011

Estimated additional contribution to dose in range 6-45%, relative to dose from ^{131}I intake (typical value ~20%)

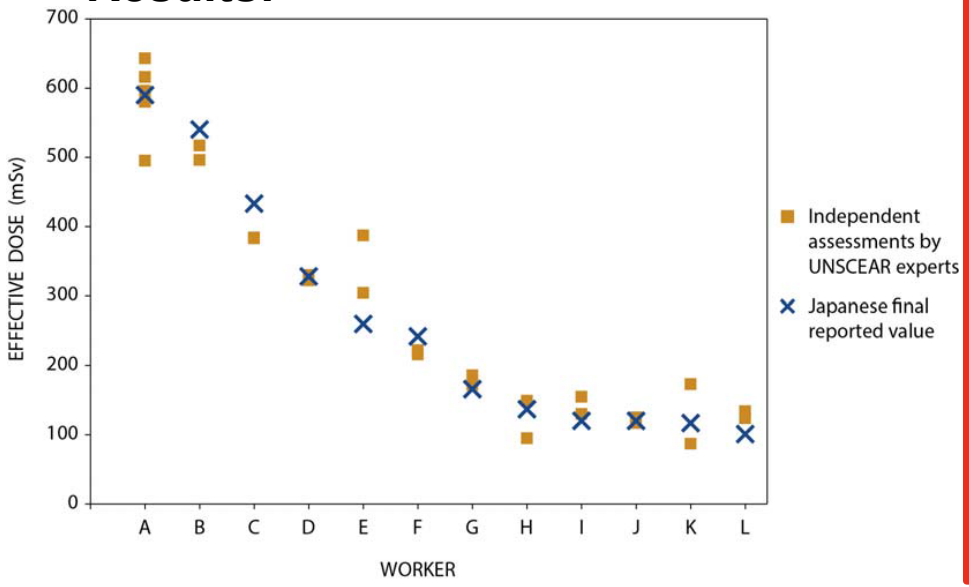
(b) Workers who commenced work after 19 March 2011

No significant additional contribution

Evaluation of reported internal doses - I

Independent assessments for 12 of the 13 workers with internal doses > 100 mSv

Results:



Short-lived radionuclides not included

Main conclusions

1. Good agreement between independent assessments and reported values
2. Internal doses were largely due to ^{131}I intakes (99%)
3. Worker A – thyroid absorbed dose ~ 12 Gy
4. Sufficient information available to provide absorbed doses to organs for health risk assessment (*thyroid, red bone marrow, colon*)

Evaluation of reported internal doses - II

Independent assessments for 42 randomly-selected workers:

- 3 dose ranges (0-5, 5-20, 20-100 mSv)
- Equal numbers of TEPCO workers and contractors
- Comprehensive information from TEPCO, less so from contractors

Main conclusions

1. Internal doses were largely due to ^{131}I intakes (98%)
2. TEPCO reported values confirmed as reliable where a positive measurement of ^{131}I in thyroid was made
3. Reliability not confirmed where the ^{131}I in thyroid measurement was below detection limit
4. Unable to confirm reliability of values reported by contractors for their workers. (However, some discrepancies were resolved after a 2013 re-assessment of doses reported in Japan. Further information would be needed to evaluate reliability.)

Reported doses for other groups of workers

13 policemen

- Reported external doses < 10 mSv
- Reported internal doses < 1 mSv

Municipal workers – *"insufficient information"*

249 firefighters

- Maximum reported external dose = 30 mSv
- Maximum reported internal dose = 1 mSv (but no reliable ^{131}I in thyroid monitoring)

Self Defense Force (military) – external dose

Location	Number of workers in dose band			
	<10 mSv	10-20 mSv	20-50 mSv	50-100 mSv
On-site	132	3	8	4
Off-site	8 453	5	-	-

Reported internal doses less than 0.2 mSv for 7 SDF workers and equal to 3.8 mSv for one on-site SDF worker

Health Risk Assessment (HRA)

"(UNSCEAR's) estimates of doses were based on a considerably expanded database and were generally within the dose ranges estimated by WHO"

"(UNSCEAR's) assumptions underpinning its estimates of health implications are generally well aligned with those of WHO"

WHO (2013). Health risk assessment from the nuclear accident after the 2011 Great East Japan earthquake and tsunami based on a preliminary dose assessment. WHO, Geneva.
http://apps.who.int/iris/bitstream/10665/78218/1/9789241505130_eng.pdf

WHO HRA Scenarios

A simple scenario approach was adopted (because individual dosimetric data were not available at the time of the WHO assessment)

Scenario	Effective dose (mSv)			Comments / assumptions
	Total	External	Internal	
1	5	5	-	Total dose, E <10 mSv; **~ 69% of workers** - Any internal dose is due to $^{134/137}$Cs inhalation, and so is homogeneous - Therefore, organ doses = effective dose
2	30	24	6	Total dose, 10 <E<100 mSv; **~ 30% of workers** Internal dose is all due to ^{131}I inhalation
3	200	200	-	External doses, E >100 mSv; **100-200 workers** - Any internal dose is due to $^{134/137}$Cs inhalation - Therefore, organ doses = effective dose - Representative of maximum doses in group
4	700	100	600	Committed effective dose >100 mSv; **12 workers** - Internal dose is all due to ^{131}I inhalation - Representative of maximum doses in group

E – effective dose - *Courtesy: Etherington, Zhang, Harrison, Walsh (IJRB, Nov. 2014)*

Estimation of absorbed dose to organs in the 1st year

Risk of leukaemia, thyroid cancer, and "all solid cancers combined" were assessed using organ doses to red bone marrow, thyroid and colon

Considered intakes: I-131(which deliver almost all the dose o the thyroid) and Cs (which deliver an approximately uniform dose across all organs)

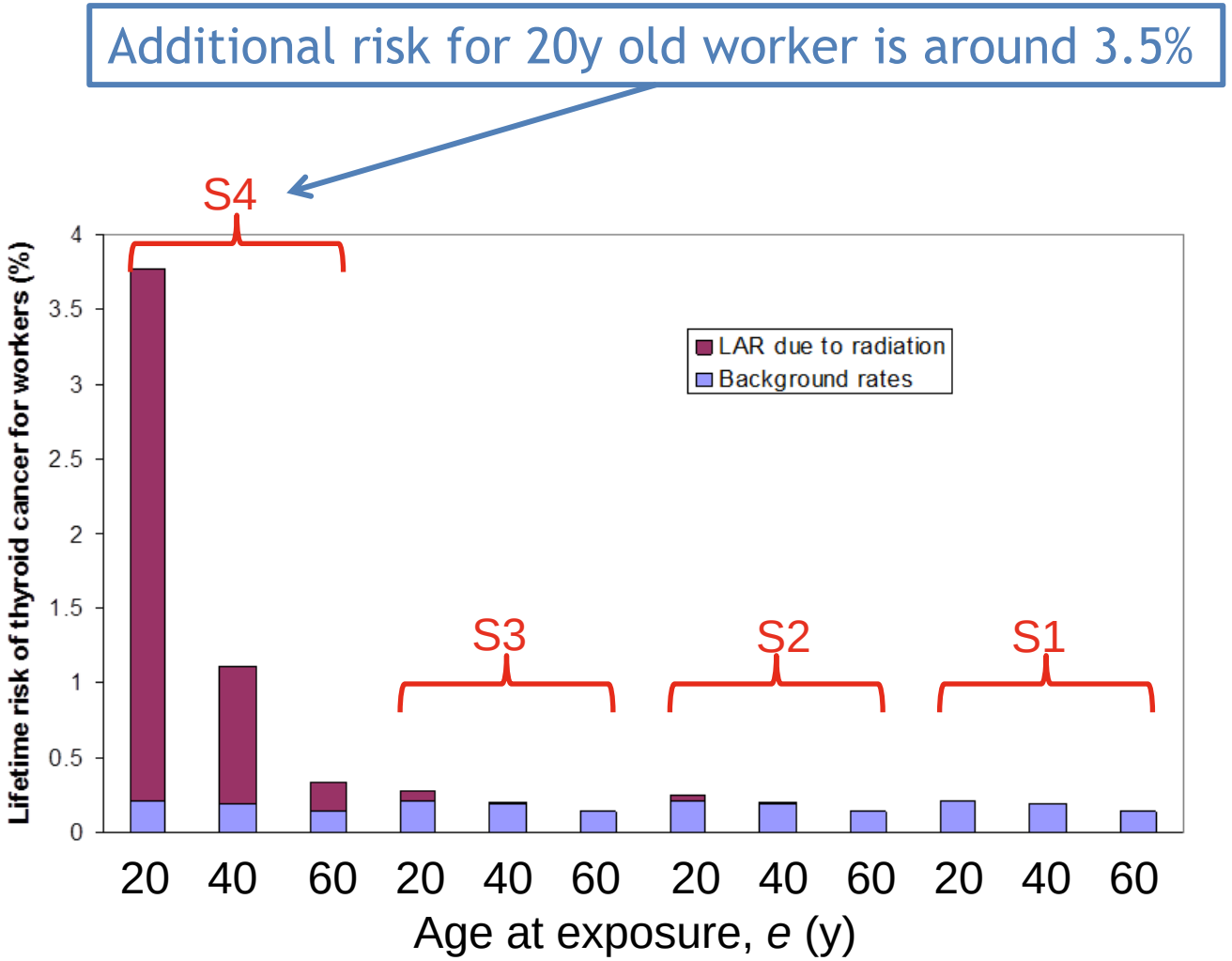
Scenario	Red bone marrow (mGy)	Thyroid (mGy)	Colon (mGy)
1	5	5	5
2	24	138	24
3	200	200	200
4	104	11 800	103

Organ doses were estimated independently for each Scenario by Anspaugh and PHE, with very similar results

Risk of thyroid cancer: Scenarios S1, S2, S3, S4

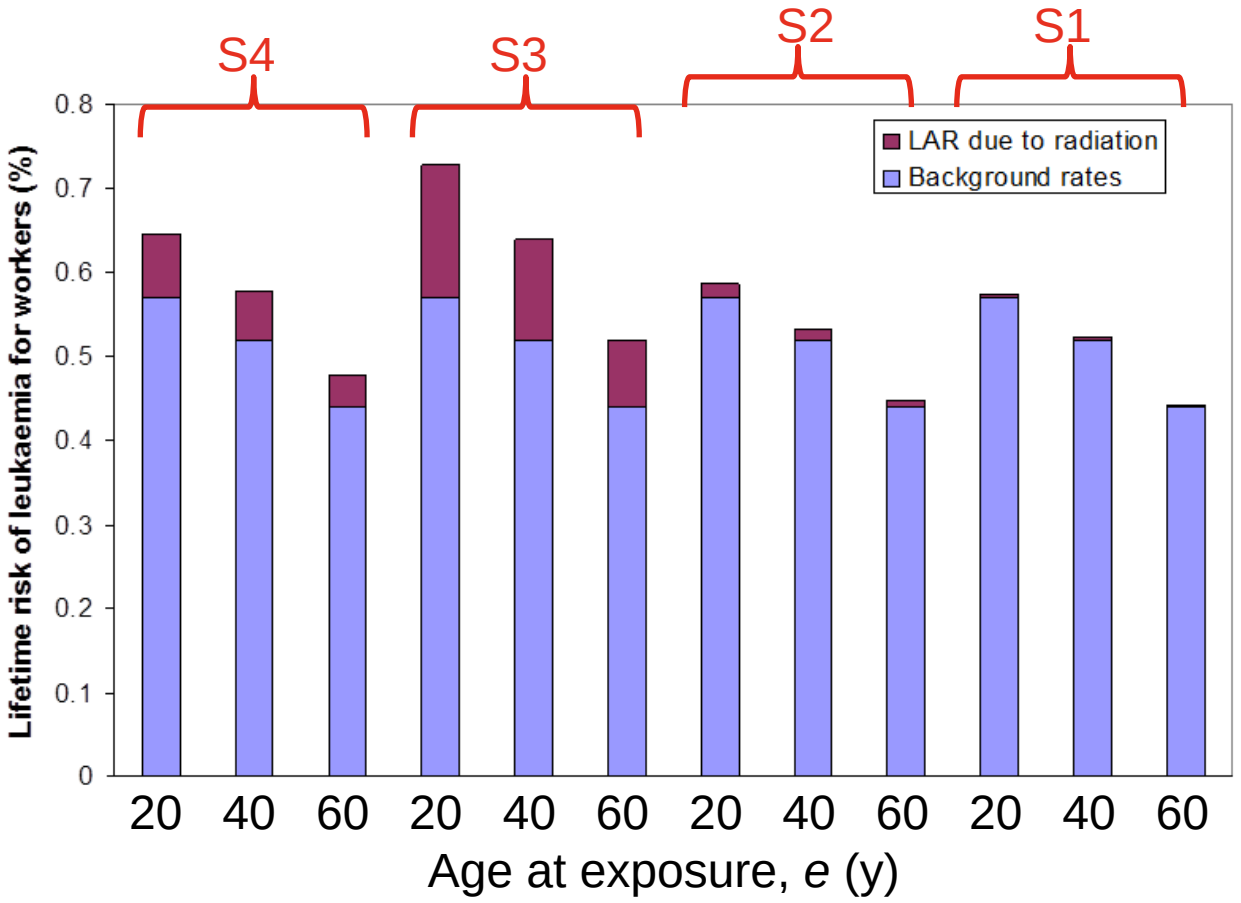
Lifetime attributable risk (LAR):

Probability of premature incidence (up to age 89y) of a cancer attributable to radiation exposure in a representative member of the population



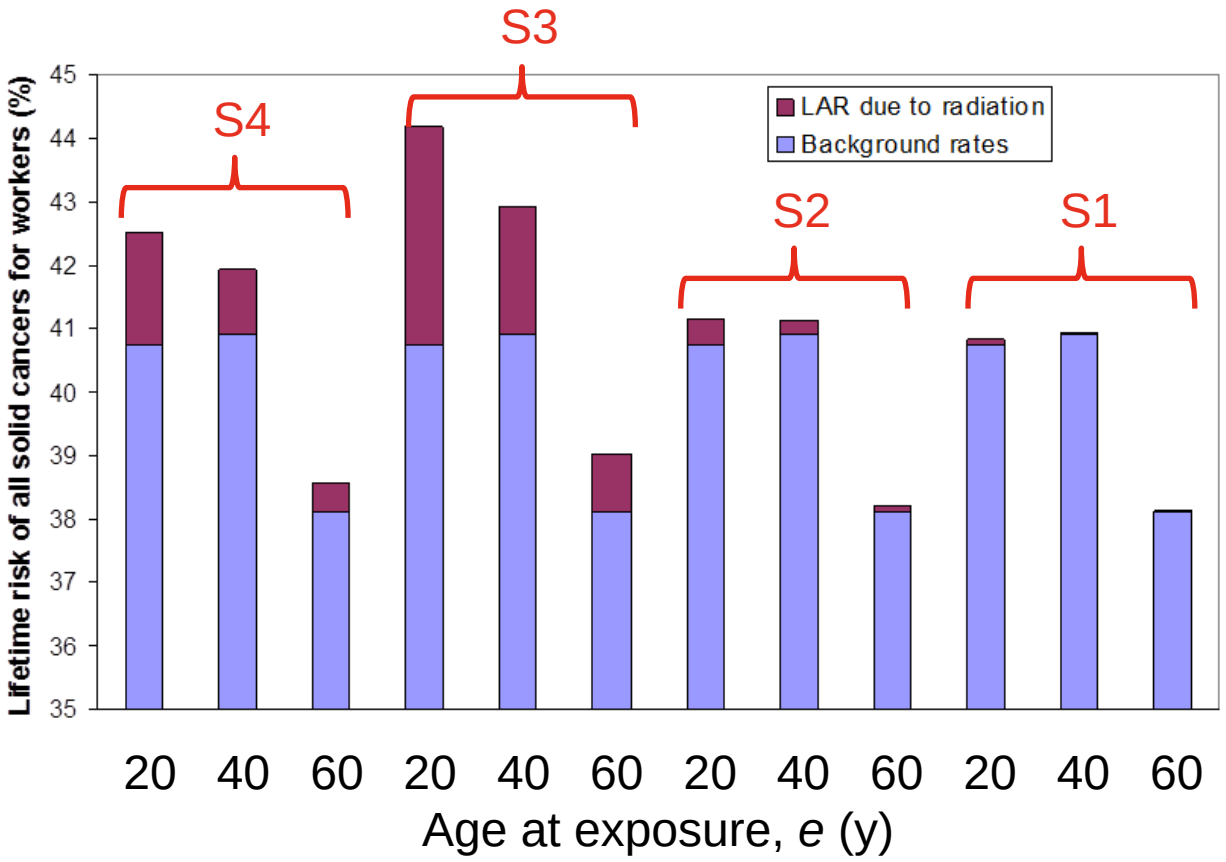
LAR – leukaemia, Scenarios S1, S2, S3, S4

Additional risks are around or even below 0.1%



LAR – all solid cancers, Scenarios S1, S2, S3, S4

Additional risks are low compared with the lifetime baseline risk of around 40% for solid cancers: excess of cancers unlikely to be observed because of variability of LBR



Non-cancer risks

- No acute health effects or deaths that could be attributed to radiation exposure have been observed
- Thirteen workers were estimated to have received absorbed doses to the thyroid in the range of 2 to 12 Gy from inhalation of ^{131}I. UNSCEAR considers that hypothyroidism is possible in the more exposed workers in this group, but the likelihood is low.
- UNSCEAR considers that risks for circulatory disease due to radiation exposure among the workers who were most exposed are very low.
- UNSCEAR considers that there is insufficient information on exposures of the eye lens of workers from beta radiation to reach an informed judgement on the risk of cataracts

Summary and Conclusions

- The highest reported total effective dose for a worker was 679 mSv (590 mSv internal, 89 mSv external).
- For the workers with the highest internal doses, the major contribution to committed effective dose was the thyroid dose resulting from inhalation of ^{131}I.
- No radiation-related deaths have been reported among FDNPP workers since the accident.
- For Scenario 4 (13 workers), LAR values for thyroid cancer up to 3.5% were estimated; a radiation-related increase in thyroid cancer incidence is unlikely to be observed because of the small number of workers.
- For Scenarios 2 & 3, a small number of cancer cases may occur, but are unlikely to be observed because of the variability in baseline rates of cancer incidence.
- For Scenario 1, any elevated radiation-related cancer risk is insignificant.
- Non-cancer risks are low.

Lessons learnt

- Monitoring systems and equipment need to be resilient to a major accident
- Individual monitoring of workers needs to be carried out promptly and provided to judge on the reliability of the dose assessment
- If capacity is severely reduced, monitoring of a limited number of workers is better than no monitoring
- The maintenance of capabilities for urine monitoring in the event of an accident (e.g. for ^{90}Sr or Pu intakes) should be considered
- The reliability of information from contractors of site operators is questionable (no individual information as of 31 October 2012)
- Capabilities for radiation monitoring and dose assessments for other ("non-radiation") categories of personnel involved in the mitigation activities in the event of a major accident should be thought in advance and set up promptly
- Access to clear and comprehensive information about the activities carried out by the first hours/days is highly desirable

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UNSCEAR assessment

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