



Ar-37, Be-7 and Xe-133 in the atmosphere

Roland Purtschert¹, Martin Kalinowski², Pierre Bourgooin², Elisabeth Wieslander², Xavier Blanchard², Robin Riedmann², Lauren Raghoo¹, Jolanta Kusmierczyk-Michulec², Abdelhakim Gheddou², Clemens Schlosser³, Yutaka Tomita⁴

¹ University of Bern, Bern, Switzerland

² CTBTO Preparatory Commission, Vienna, Austria

³ Bundesamt für Strahlenschutz, Germany

⁴ Japan Atomic Energy Agency, Japan

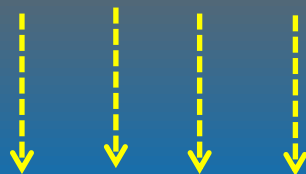
- Ar-37 in soil air is included in the OSI verification regime
- Ar-37 measurements in the atmosphere at locations close to IMS stations can
 - provide information of Ar-37 concentrations in atmospheric air (both background & elevated)
 - give insights of possible seasonal effects
 - be correlated with simultaneous Xe-133 measurements in the atmosphere
 - with its 35 day half-life provides information about atmospheric circulation pattern on timescales between Pb-212 (10.6 h) and Be-7 (53.3 days)

Natural atmospheric Ar-37 level in low troposphere (Bern)

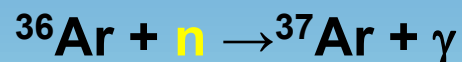
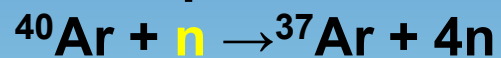
 $T_{1/2}: 35d$

Stratosphere

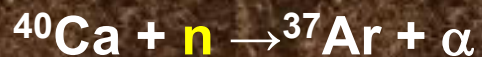
Cosmic rays



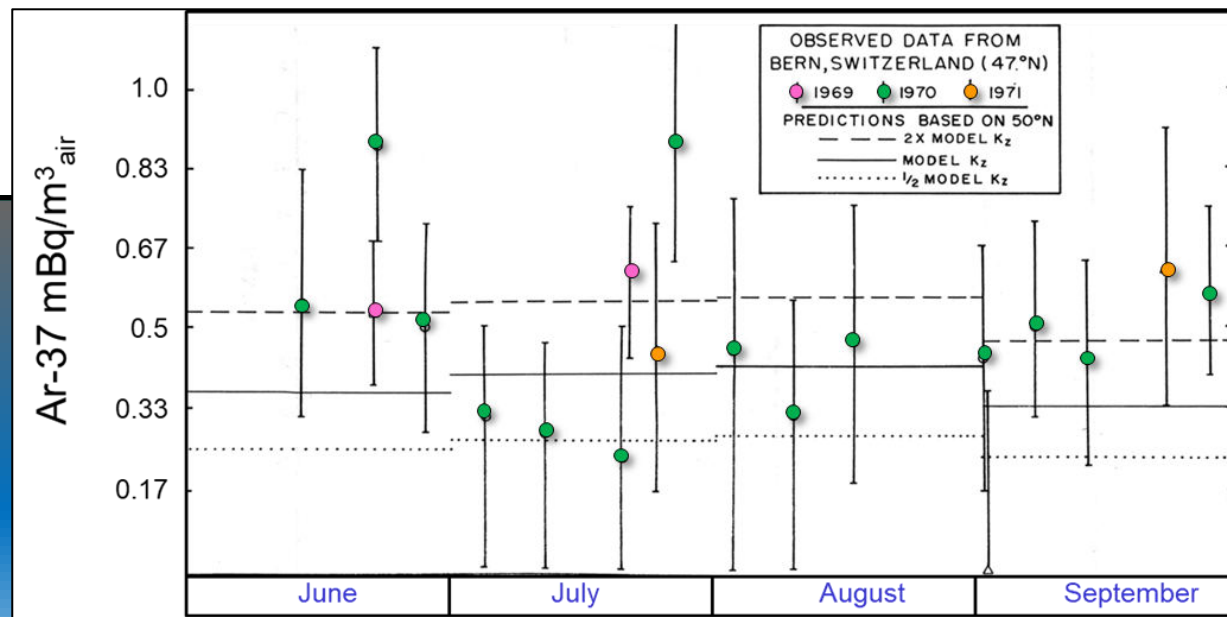
Atmosphere



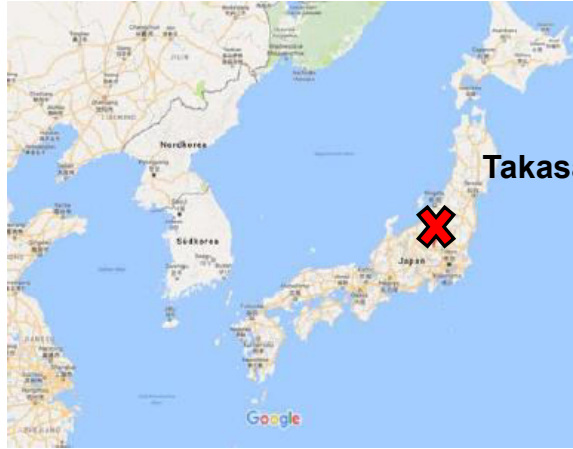
Background low troposphere:
0.5-1 mBq/m³_{air}



Lithosphere



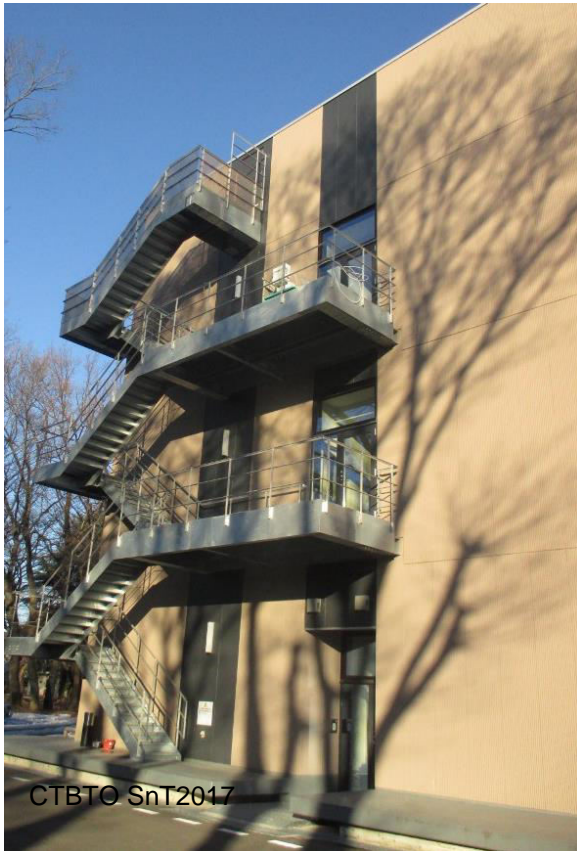
Loosli, 1972



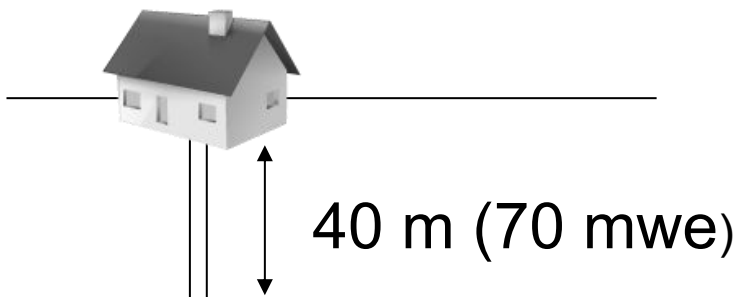
Takasaki station



Acknowledgment: Sampling carried out
Yutaka Tomita (IMS Radionuclide Station)



- On-Site Inspection (OSI) noble gas (NG) sampling equipment was used to collect atmospheric gas samples for Ar-37
- Sample bags were shipped to Low-Level Counting laboratory at University of Bern, Switzerland for activity measurements



CTBTO SsT2017

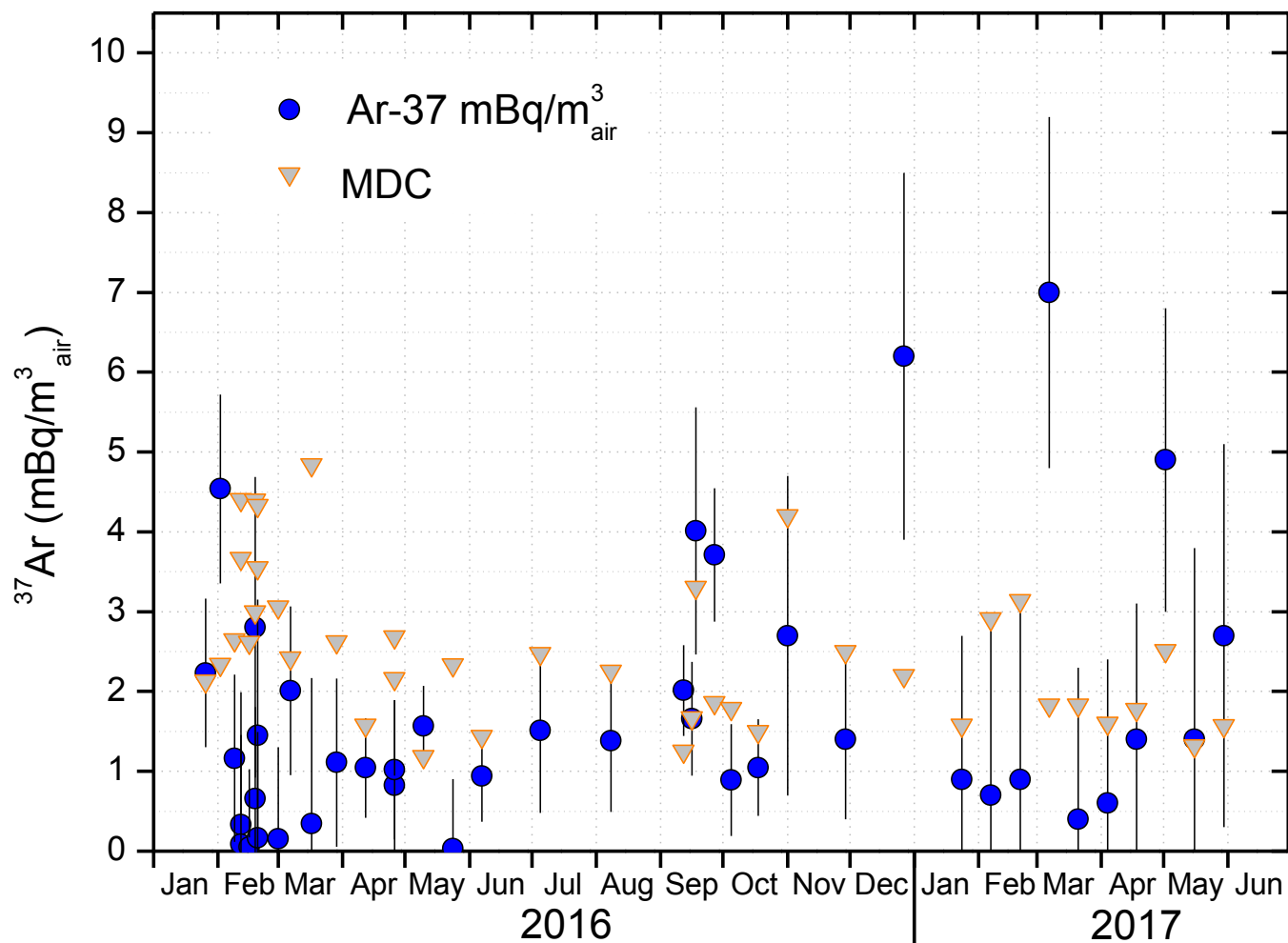
Counting arrangement

- Sample size 80-100 L
- Shipping time 1-2 weeks
- Measuring time 0.5-1 week
- Counter volume 50-100 cm³
- MDC 0.7-3 mBq/m³_{air}



Sample bag in separation laboratory

Takasaki Ar-37 Results (Jan 2016-May 2017)



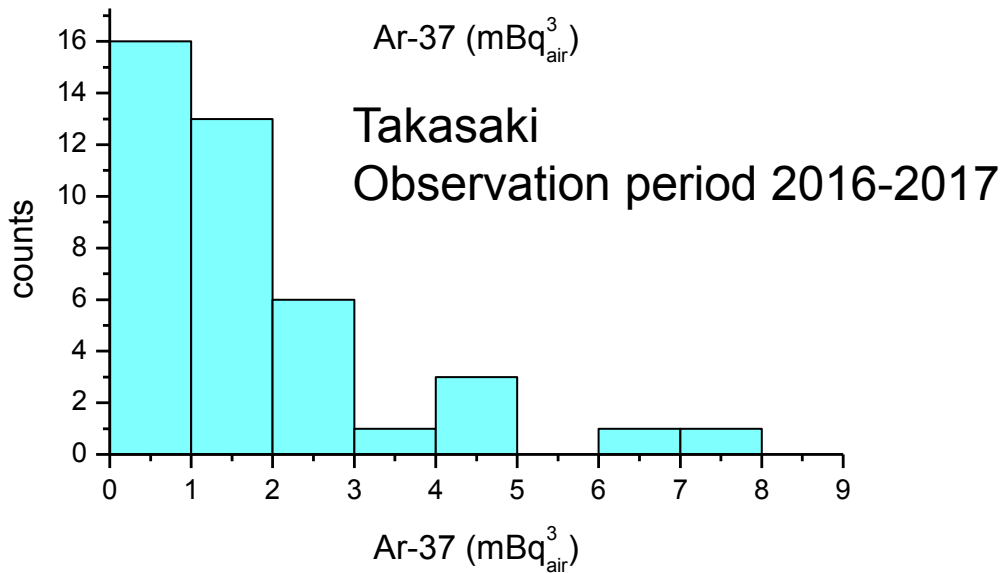
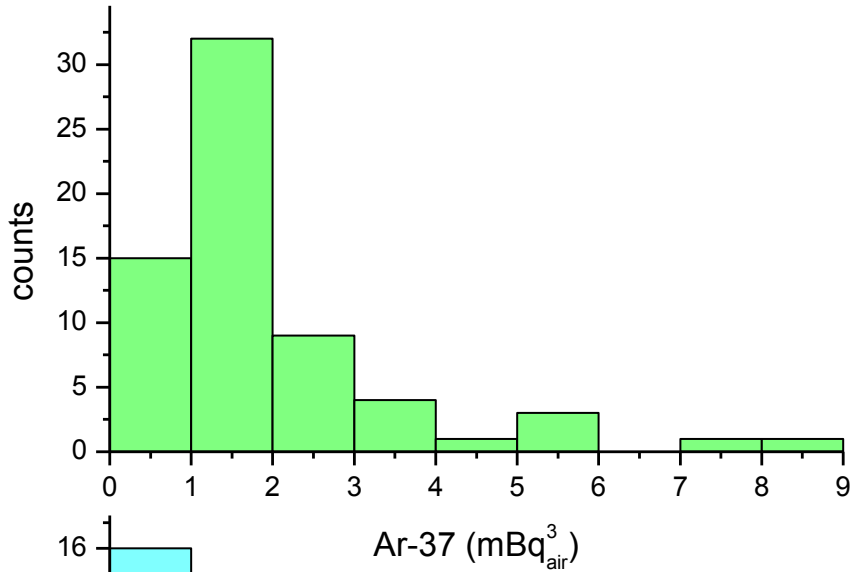
- 1-2 samples per month
- Samples cover a full seasonal cycle
- Most values close or below MDA
- No activities above 9 mBq/m³ including periods after the two DPRK tests in 2016



DPRK Tests



Bern
Observation period 2008-2016



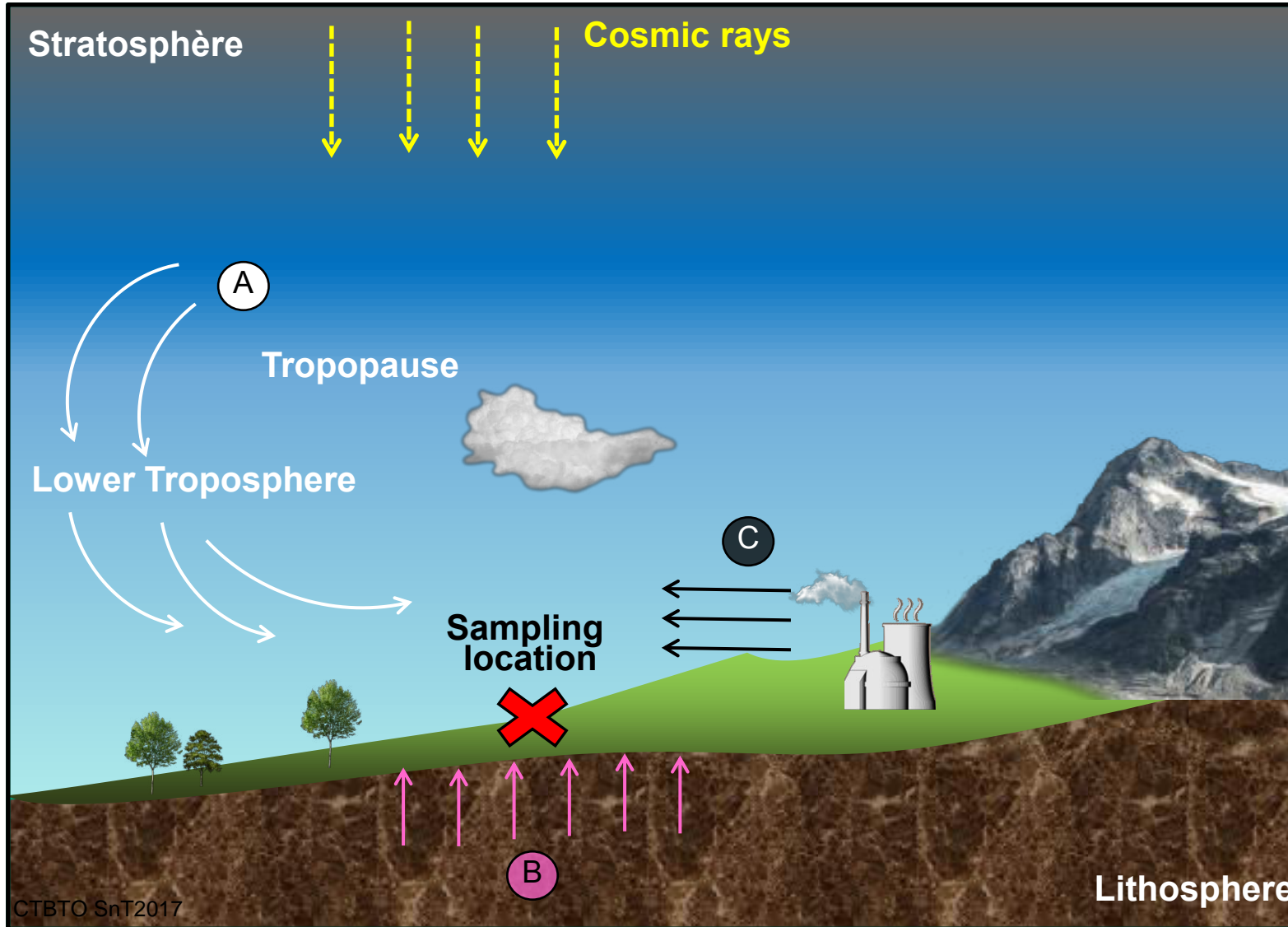
No of samples	Mean	Median	Std Deviation
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70	1.8	1.4	1.6
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41	1.7	1.2	1.6
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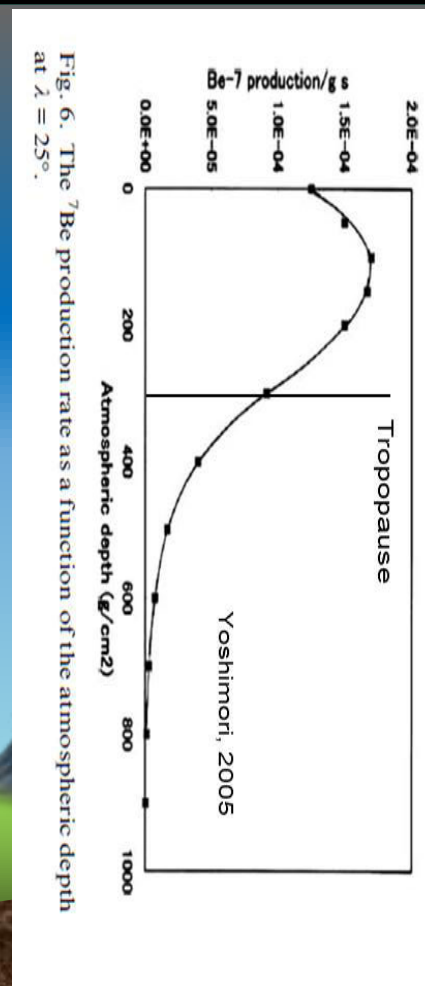
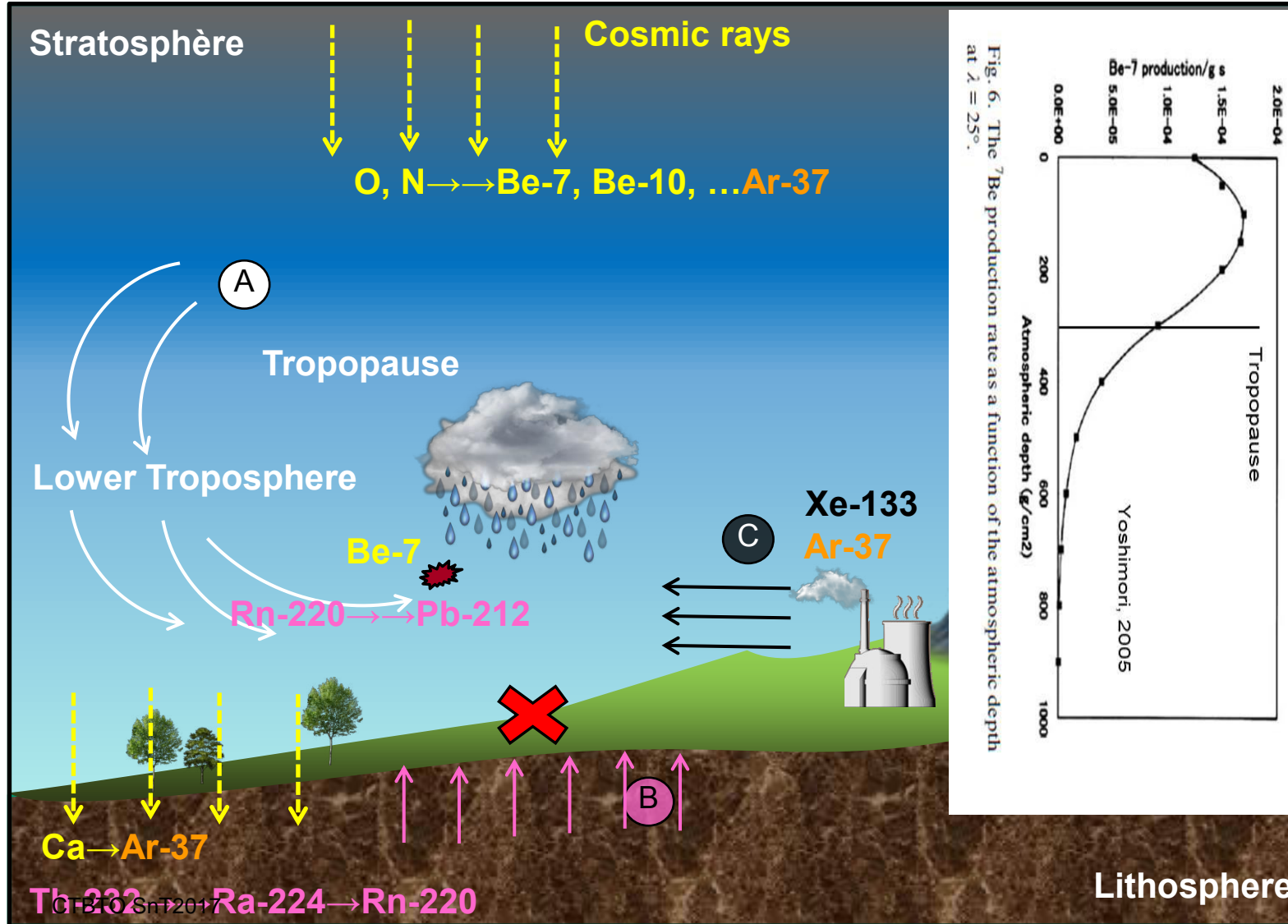
Possible sources for observed variations

- (A) In-flow of stratospheric air masses
- (B) Outgassing of soil air
- (C) Emissions from nuclear installations



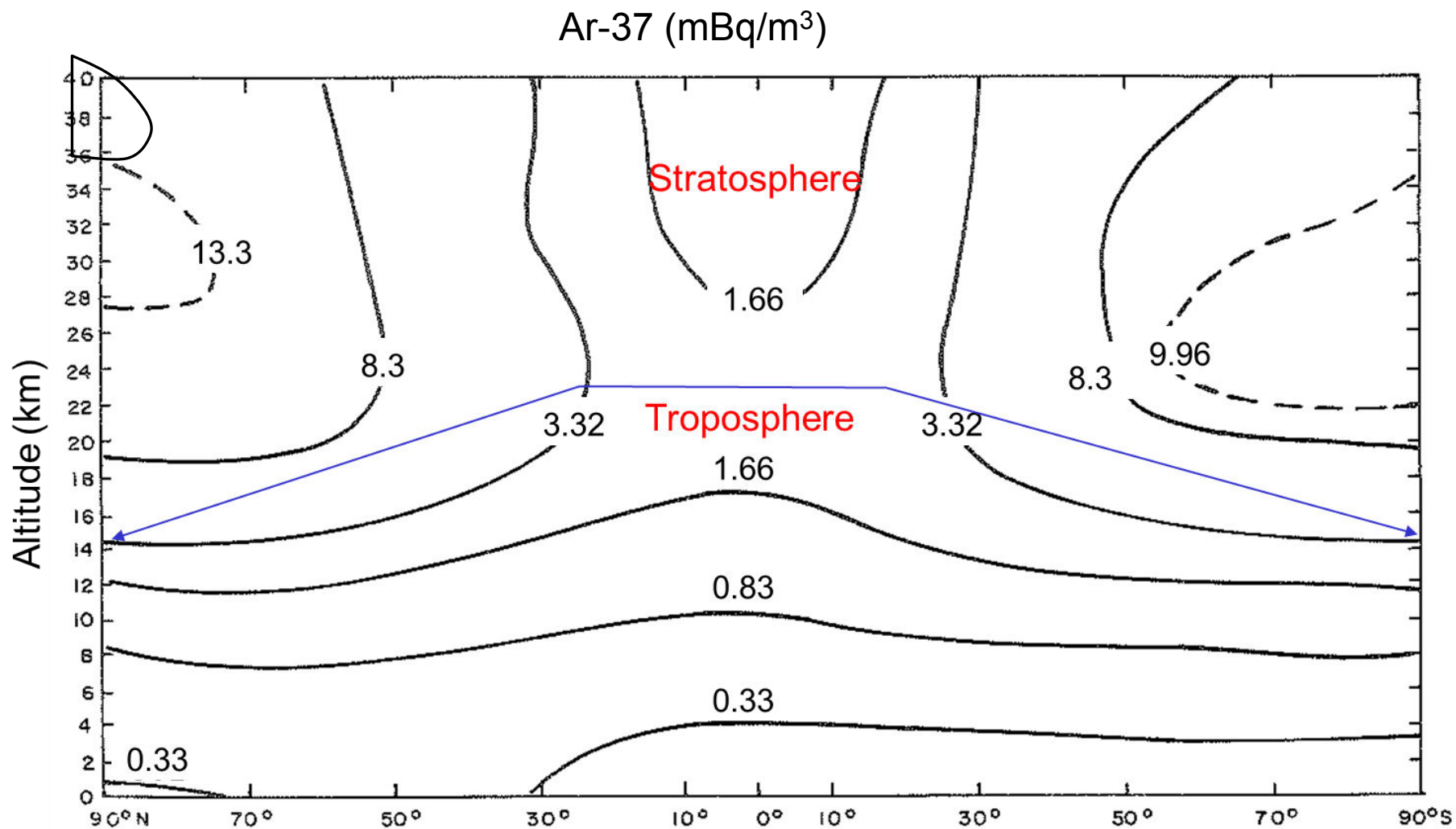
Sources and Indicators

- (A) In-flow of stratospheric air masses
- (B) Outgassing of soil air
- (C) Emissions from nuclear installations

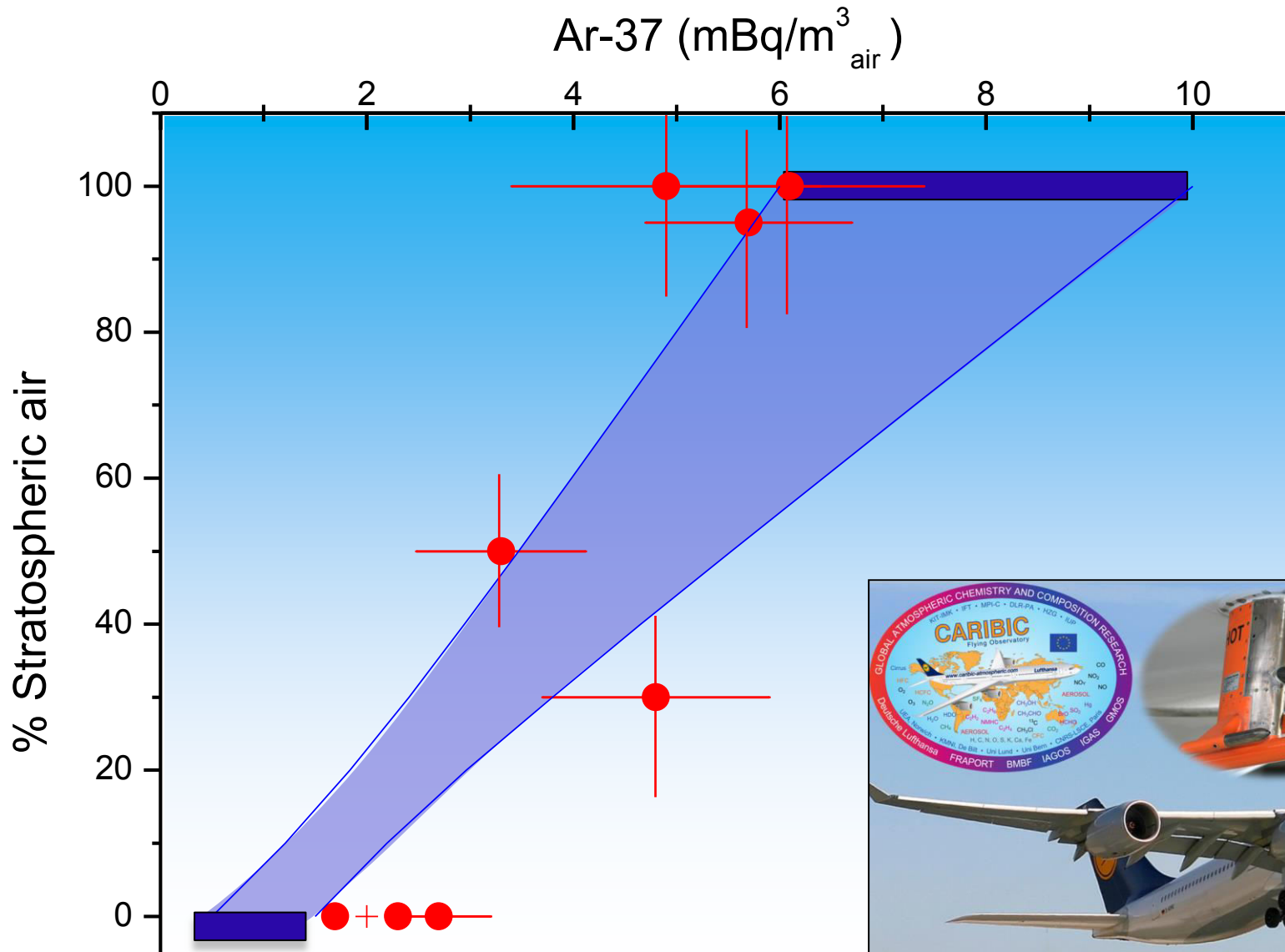


- (A) **Be-7** ($T_{1/2}$: 53.3 d)
- (B) **Pb-212** ($T_{1/2}$: 10.6 h)
- (C) **Xe-133** ($T_{1/2}$: 5.2 d)

Ar-37 in the stratosphere: Theory



Ar-37 in the stratosphere: Measurements



Data

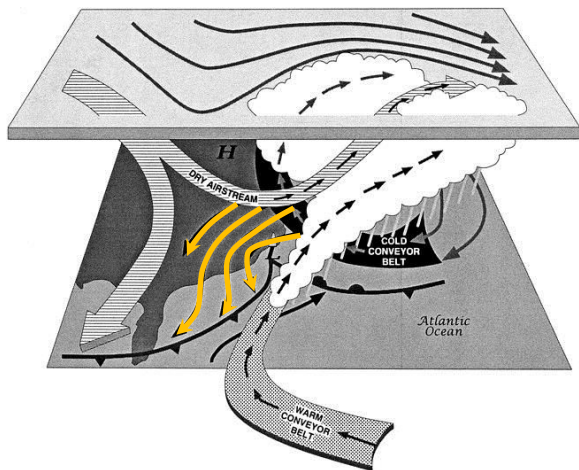
CTBTO SnI 2017

Low Troposphere (2010-2015)

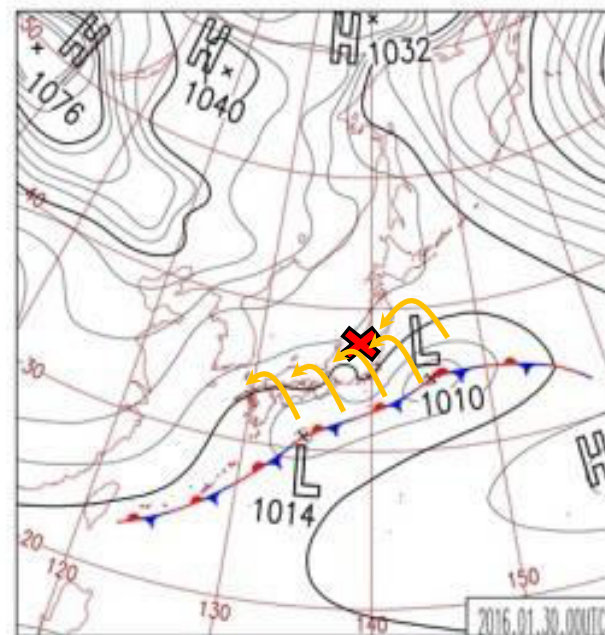


Lal and Peters 1962, Loosli 1980 et al., Machta 1973
Loosli 1980 et al., Currie 1980

Stratospheric vertical transport: Supporting weather conditions



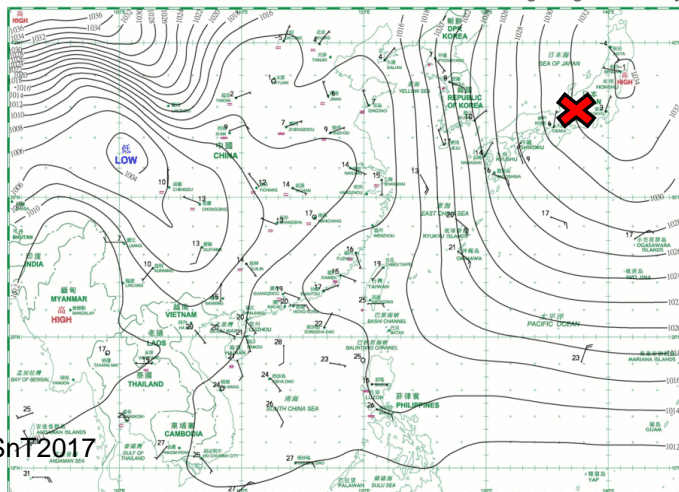
Idealized vertical motions associated with a well-developed cyclonic (low pressure) system



Surface pressure pattern leading to the high concentration observed on 2 February 2016.

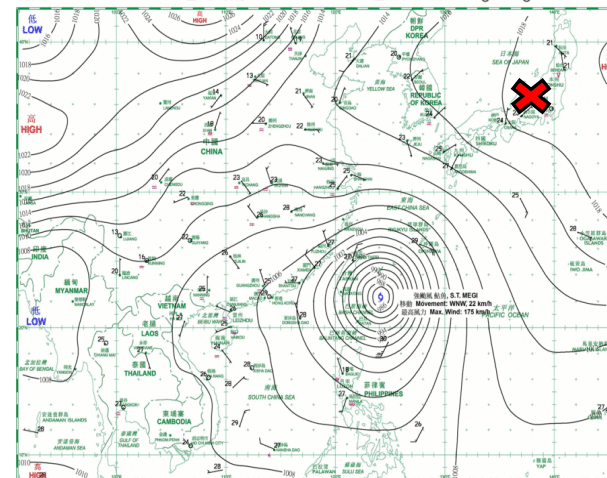
Low activity situation

日期/Date: 12.02.2016 香港時間/HK Time: 02:00 香港天文台 Hong Kong Observatory



High activity situation

日期/Date: 27.09.2016 香港時間/HK Time: 02:00 香港天文台 Hong Kong Observatory



Correlation with weather situation

Ar-37 < 2 mBq/m³_{air}

Date	Ar-37 (mBq/m ³)	Weather Pattern
12 Feb 2016	0.33/0.09	Strong anticyclonic system
16 Feb 2016	0.05	Strong anticyclonic system
19 Feb 2016	2.80/0.66	Anticyclonic system
20 Feb 2016	1.45/0.17	Anticyclonic system
01 Mar 2016	0.16	Strong anticyclonic system
17 Mar 2016	0.34	Anticyclonic system
26 Avr 2016	0.82/1.02	Weak weather pattern
24 May 2016	0.03	Anticyclonic system
07 Jun 2016	0.94	Weak anticyclonic system
05 Oct 2016	0.89	Anticyclonic system
24 Jan 2017	0.9	Strong anticyclonic system
07 Feb 2017	0.7	Strong anticyclonic system
21 Feb 2017	0.9	Strong anticyclonic system
21 Mar 2017	0.4	Deep cyclonic system south of Japan
04 Avr 2017	0.6	Strong anticyclonic system

anticyclonic system H

 strong

 Weak, moderate

cyclonic system L

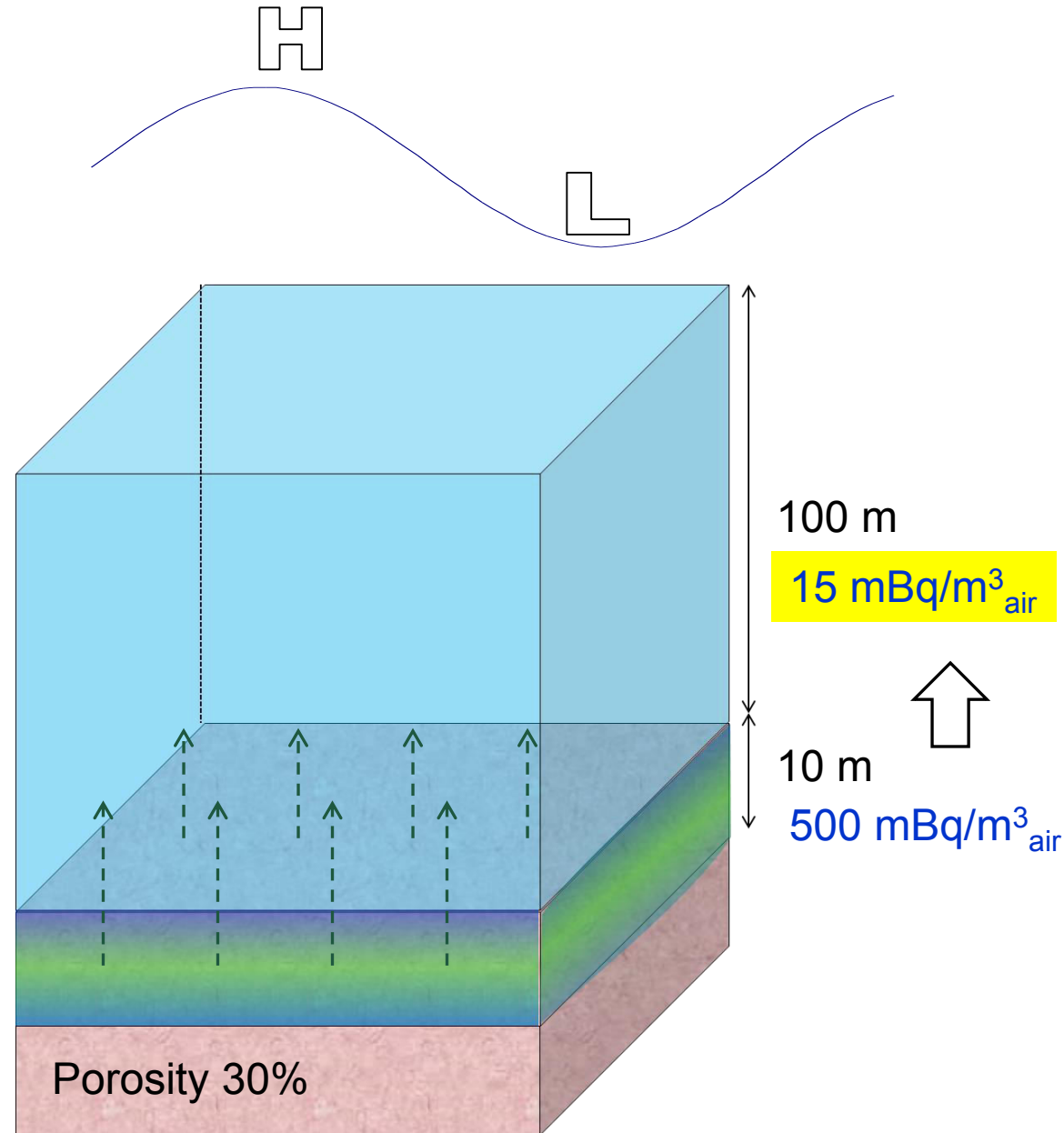
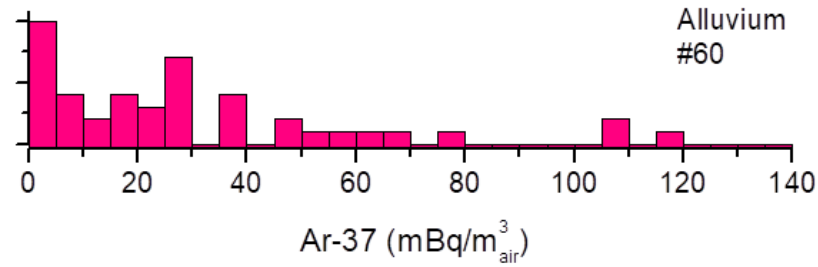
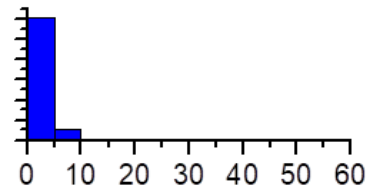
 strong

 Weak, moderate

Ar-37 > 3 mBq/m³_{air}

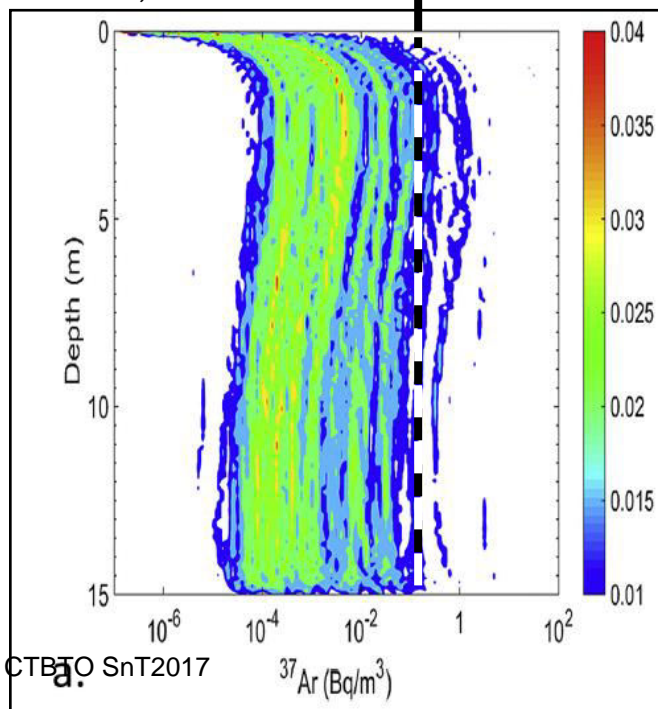
Date	Ar-37 (mBq/m ³)	Weather Pattern
02 Feb 2016	4.54	A cyclonic system with a trough crossing the area over a period of several days
18 Sep 2016	4.01	A cyclonic system with a trough crossing the area over a period of several days, typhoon over East China Sea
27 Sep 2016	3.71	Ridge of high pressure, typhoon over East China Sea
27 Dec 2016	4.90	Vigorous trough over the area, typhoon far over South China Sea
07 Mar 2017	7.0	Sharp trough moving out of Japan early in the day
02 May 2017	4.9	Sharp trough moving out of Japan early in the day

Exhalation of gasses from soil column: Extreme scenario



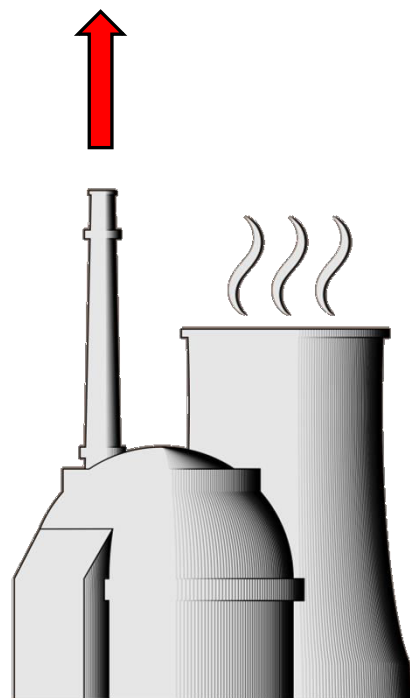
Guillon et al, 2016

500 mBq/m³_{air}



Emissions from Nuclear Power Plants

	BWR	PWR
Power (MW)	400	1400
³⁷ Ar at stack (Bq/m ³ _{Luft})	27 ± 3	22 ± 3
³⁷ Ar/power (Bq/m ³ _{Luft} /GW)	~70	~20
Air stream (m ³ /h)	300'000	330'000
Emission rate	~8 MBq/h	~8 MBq/h

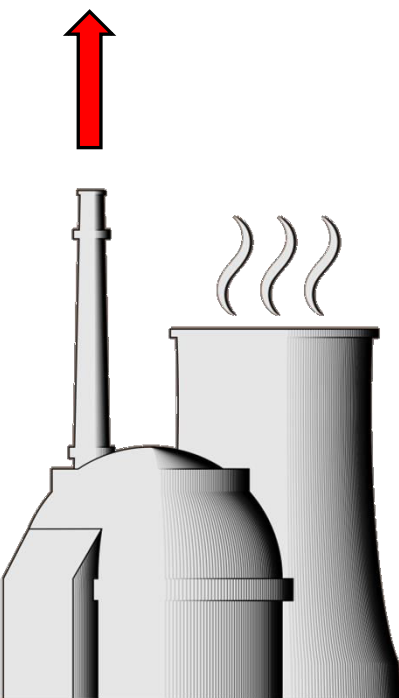


(Joint Uni Bern–BfS Ar-37
Project for Noble Gas
Measurements)
from Stack Samples

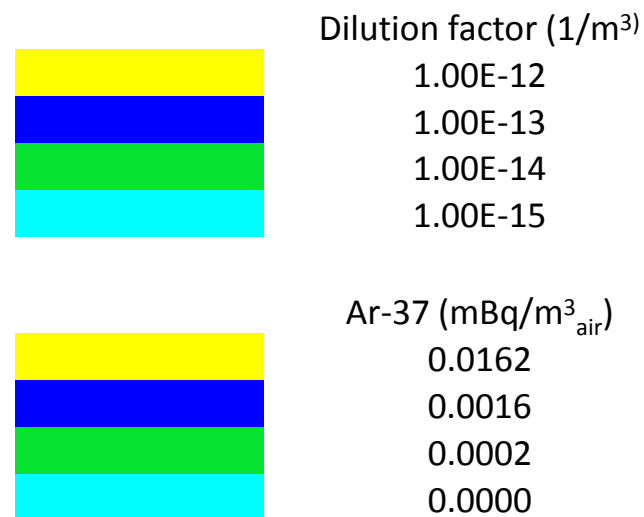
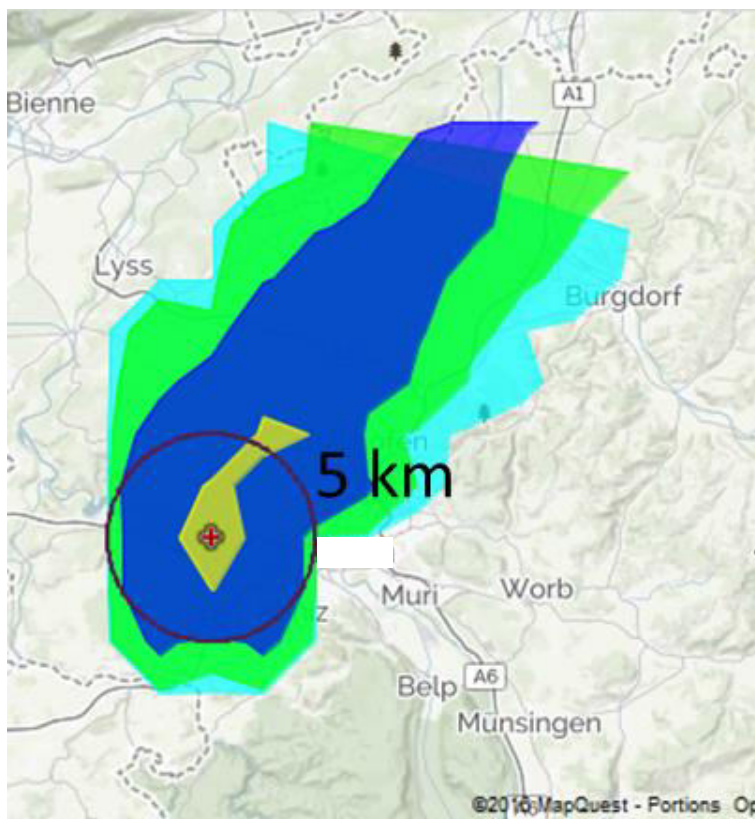
Sampling at stack

Emissions from Nuclear Power Plants

300'000 m³/h
with 25 Bq/m³
~8 MBq/h



	BWR	PWR
Power (MW)	400	1400
³⁷ Ar at stack (Bq/m ³ _{Luft})	27 ± 3	22 ± 3
³⁷ Ar/power (Bq/m ³ _{Luft} /GW)	~70	~20
Air stream (m ³ /h)	300'000	330'000
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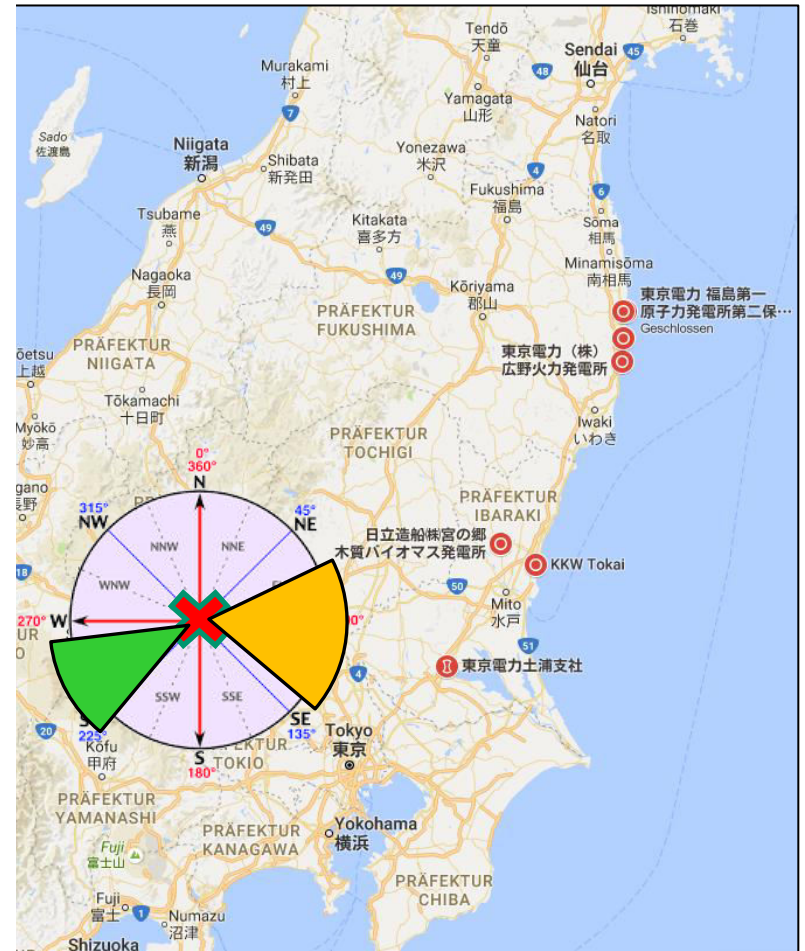
Wind direction



Map of nuclear power plants

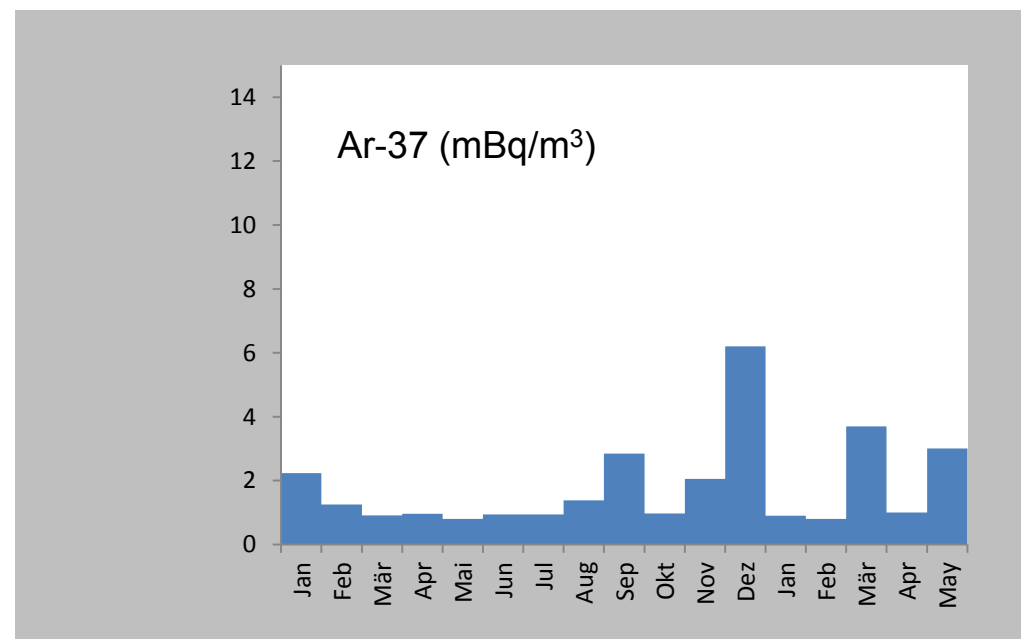
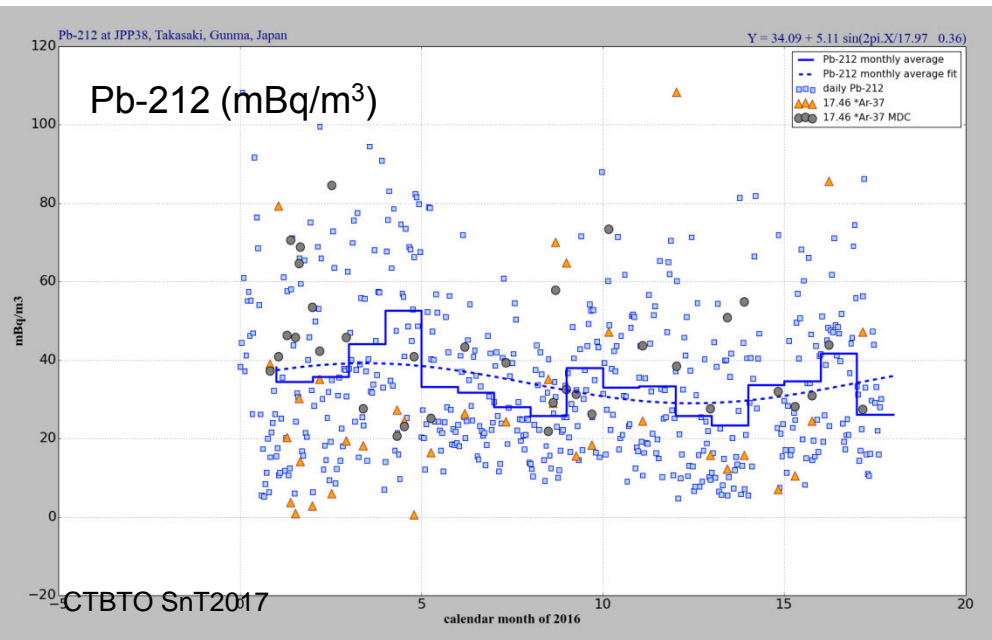
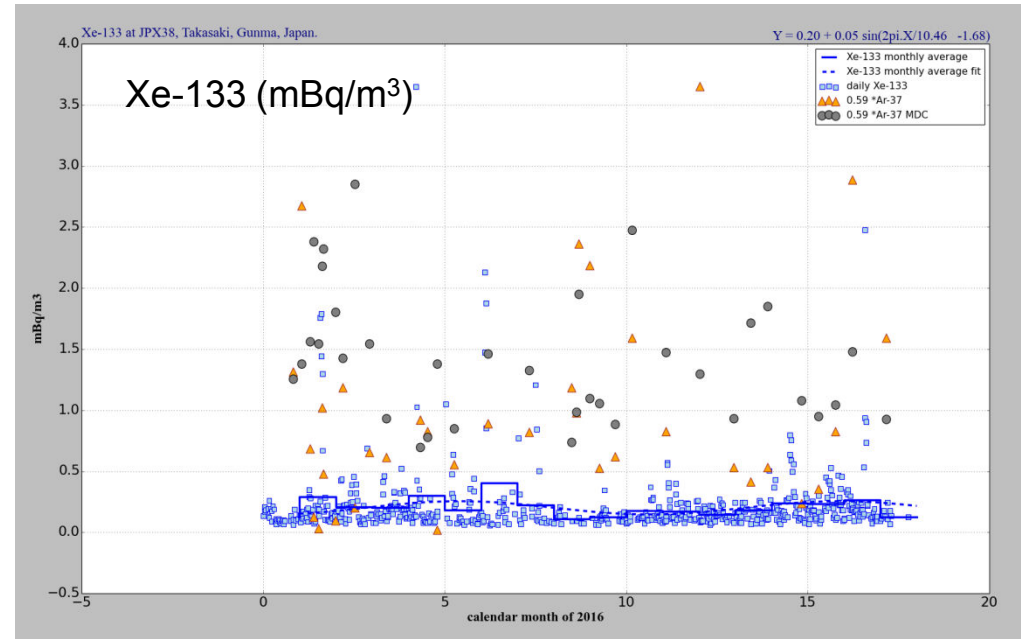
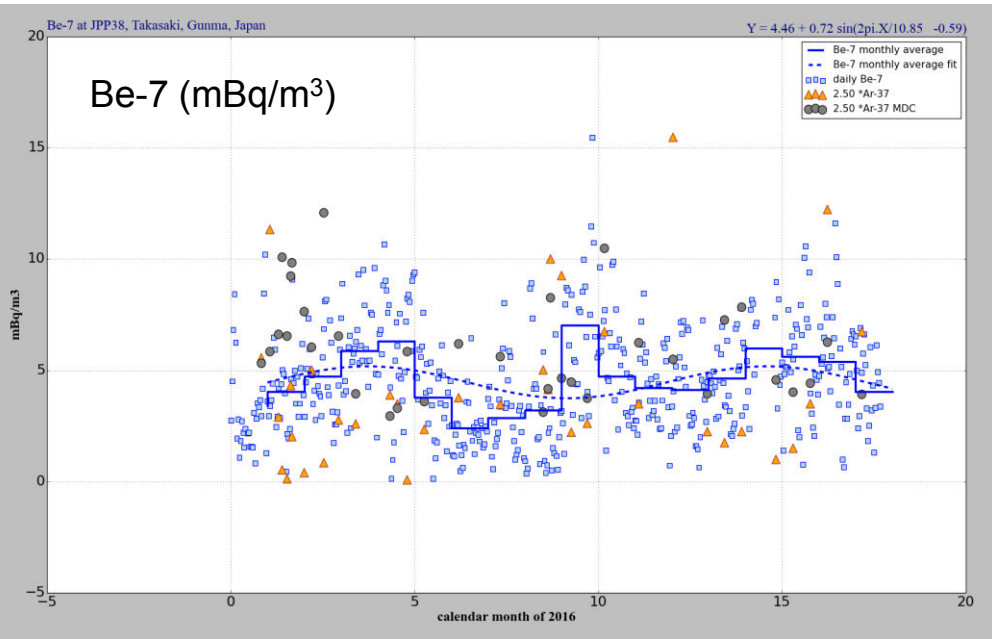
Nuclear power plants in Japan (view)

- Active plants
- Inactive plants
- Planned plants



Not conclusive

Temporal pattern of potential indicators (monthly means)

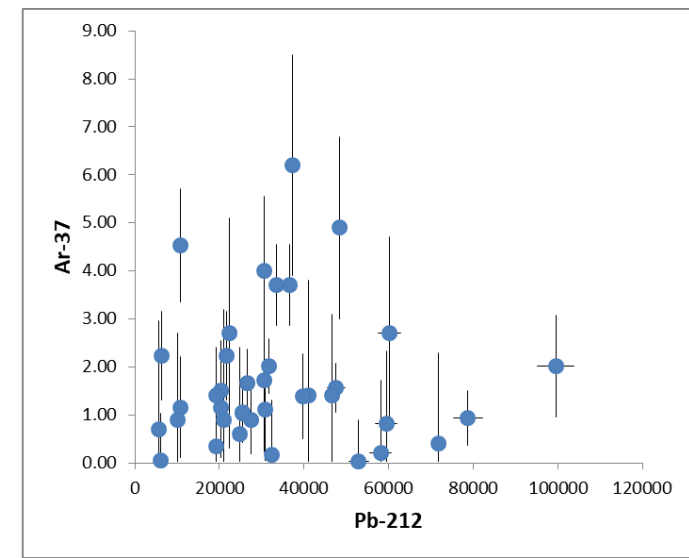
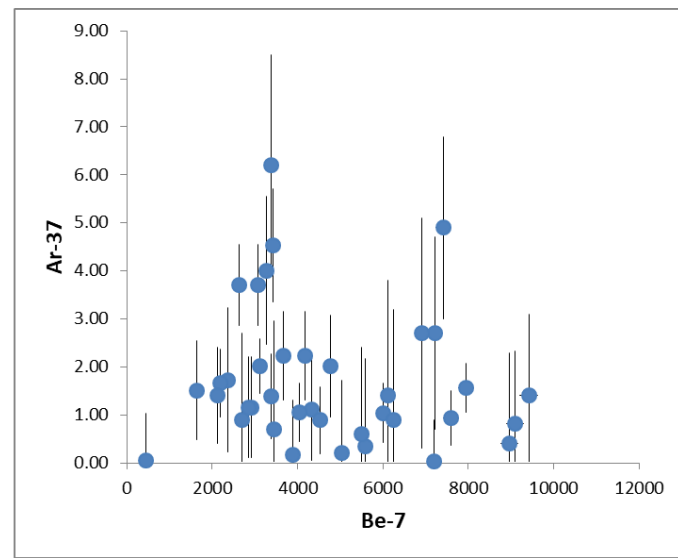
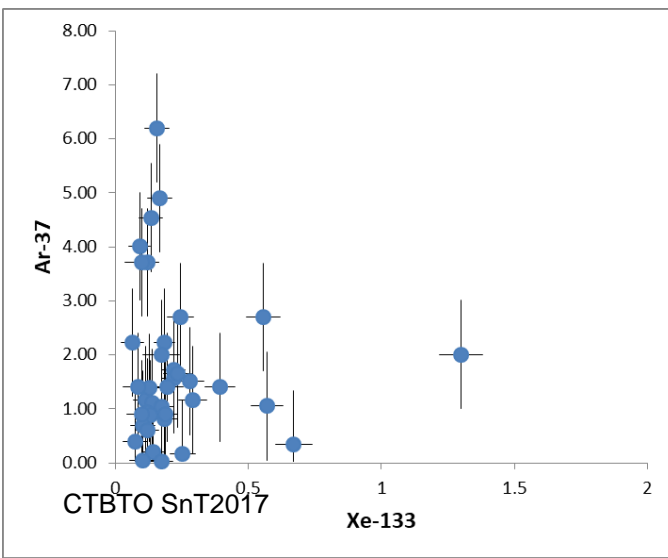
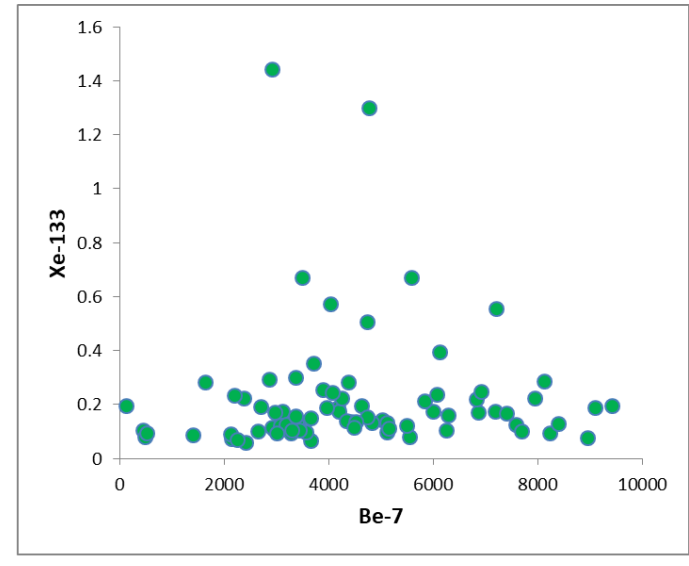
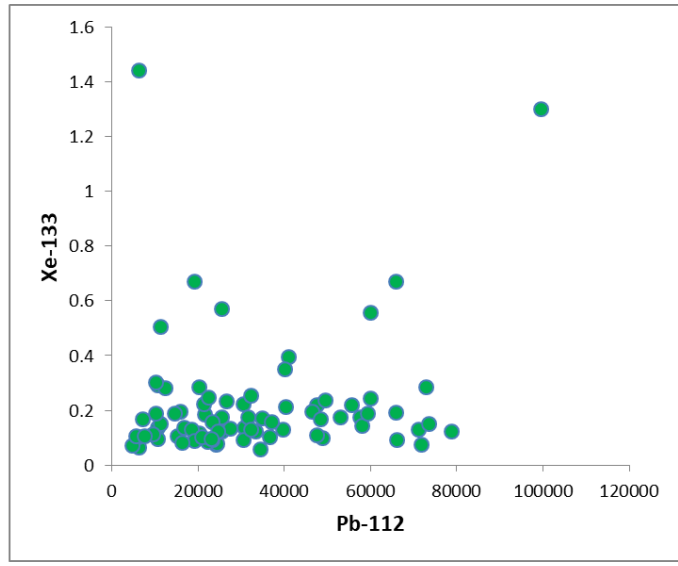
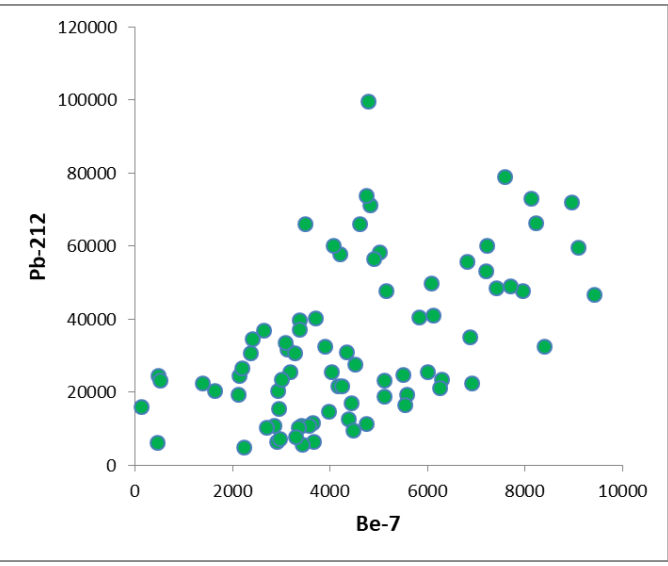


Correlations?

Measurements from Takasaki (Jan 2016 - May 2017)

Pb-112, Be-7 (uBq/m³)

Xe-133, Ar-37 mBq/m³)



- The first time a long and extensive record of tropospheric Ar-37 activity concentrations at the location of an IMS station was measured
- All values measured range between 1-10 mBq/m³_{air} in agreement with numbers found elsewhere
- Three potential sources for slightly elevated background values were discussed
 - Influence of stratospheric vertical transport
 - Emanation of gases from soils
 - Emissions from power plants
- Source strengths are likely low for all three scenarios, which is also demonstrated by the missing correlation with all source indicators Be-7, Pb-212 and Xe-133
- More investigations are needed in particular for the characterisation of emissions from nuclear installations (► [next talk Heise et al](#))
- The absence of activity concentrations significantly above the natural background demonstrate the potential of Ar-37 as an conclusive source discriminator in high background areas (► [talk Bowyer](#))