The issue of C_3F_8 activation

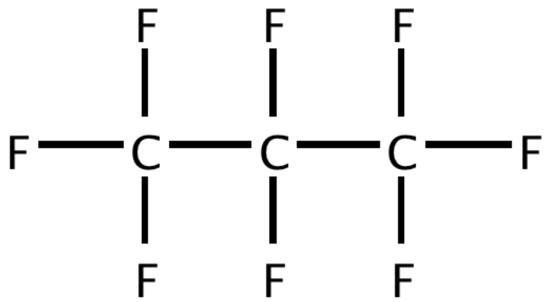
Activation calculations were performed for radiological protection purposes. The summary of the calculations is presented for the purpose of discussing the proper management of the C_3F_8 cooling system.

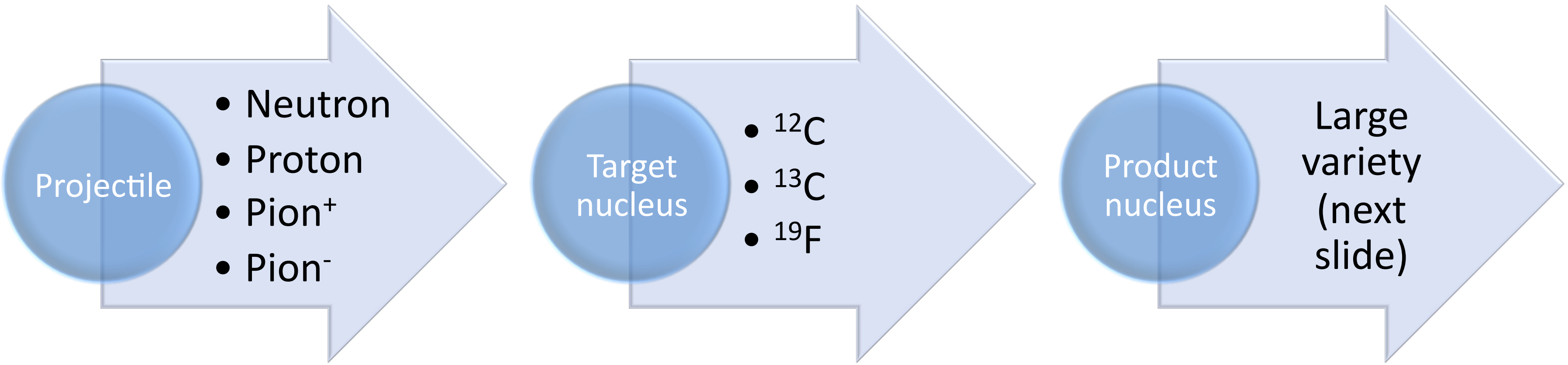
Outline

1. Nuclear reactions and their products
2. Exposure to radiation outside of the tank in the USA 15
3. Inhalation exposure in case of a fluorocarbon leak

The radiation environment in the inner detector is such that spallation reactions are dominating the activation.

NUCLEAR REACTIONS AND THEIR PRODUCTS


F
F C C C F
F


Projectile
Neutron
Proton
Pion+
Pion-
Target nucleus
12C
13C
19F
Product nucleus
Large variety (next slide)

Radioactive products **Stable products**

^{3}H	12.3 y	^{9}Li	180 ms	^{16}N	7 s	^{1}H	^{15}N
^{10}Be	1.5 My	^{11}Be	14 s	^{17}N	4 s	^{2}H	^{16}O
^{11}C	20 min	^{12}Be	20 ms	^{13}O	9 ms	^{3}He	^{17}O
^{14}C	5700 y	^{8}B	770 ms	^{17}F	65 s	^{4}He	^{18}O
^{13}N	10 min	^{12}B	20 ms	^{20}F	11 s	^{6}Li	^{19}F
^{14}O	71 s	^{13}B	17 ms	^{18}Ne	2 s	^{7}Li	
^{15}O	122 s	^{14}B	13 ms	^{19}Ne	17 s	^{9}Be	
^{19}O	27 s	^{9}C	130 ms			^{10}B	
^{18}F	110 min	^{10}C	110 fs			^{11}B	
^{6}He	800 ms	^{15}C	3 s			^{12}C	
^{8}He	120 ms	^{16}C	1 s			^{13}C	
^{8}Li	840 ms	^{12}N	11 ms			^{14}N	

Summary

- "Production yield": the number of nuclei of a given nuclide produced per second in the fluorocarbon
  - Amount of fluorocarbon in the inner detector
  - Its spatial distribution
  - Luminosity
- The production yield is different for different products (certain final states are more likely than others), e.g.
  - For the radionuclides on the right, the decreasing order by production rate in otherwise equal conditions is: ^{3}H, ^{18}F, ^{11}C, ^{7}Be, ^{14}C, ^{10}Be, ^{15}O, ^{13}N, ^{19}O, ^{14}O. The production rate of ^{3}H is about 3 orders of magnitude higher than ^{14}O .
  - In general, the production rate is higher for nuclides closer to the target nuclide and closer to the stability line. ^{3}H as a small fragment is copiously produced.
- Activity depends on the production yield and half-life

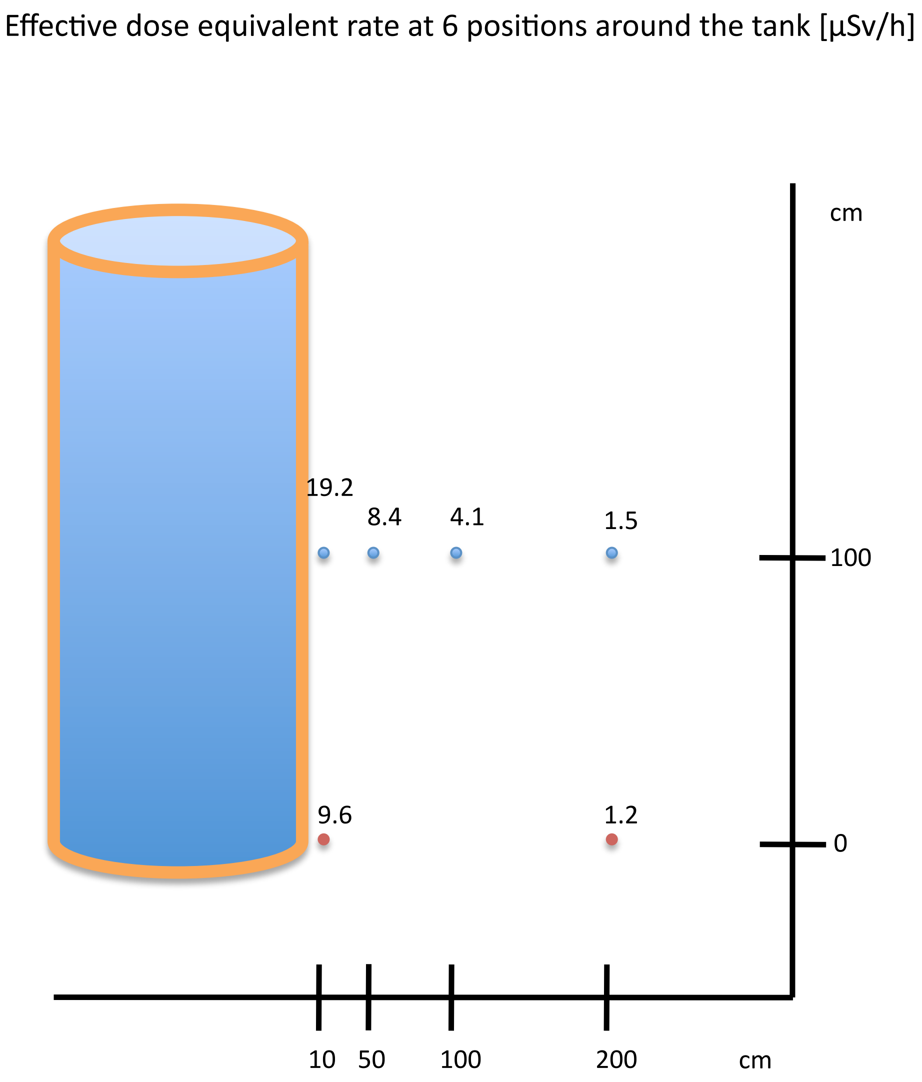
Short-lived		Long-lived	
^{11}C	20 min	^{3}H	12.3 y
^{18}F	110 min	^{7}Be	53 d
^{13}N	10 min	^{10}Be	1.5 My
^{14}O	71 s	^{14}C	5700 y
^{15}O	122 s		
^{19}O	27 s		

The activated fluorocarbon accumulates in the tank in USA 15. The decay radiation penetrates the tank walls and delivers a certain dose to a person in the vicinity

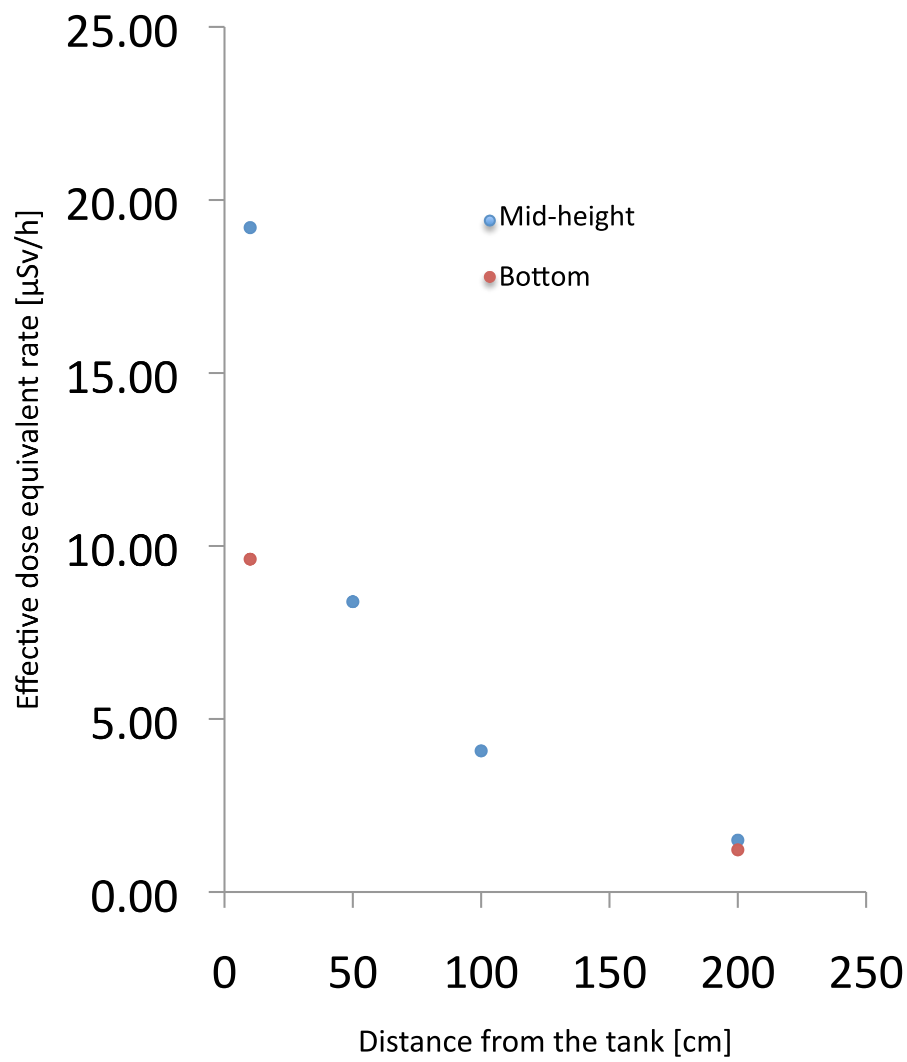
EXPOSURE TO RADIATION OUTSIDE OF THE TANK IN USA15

Source terms

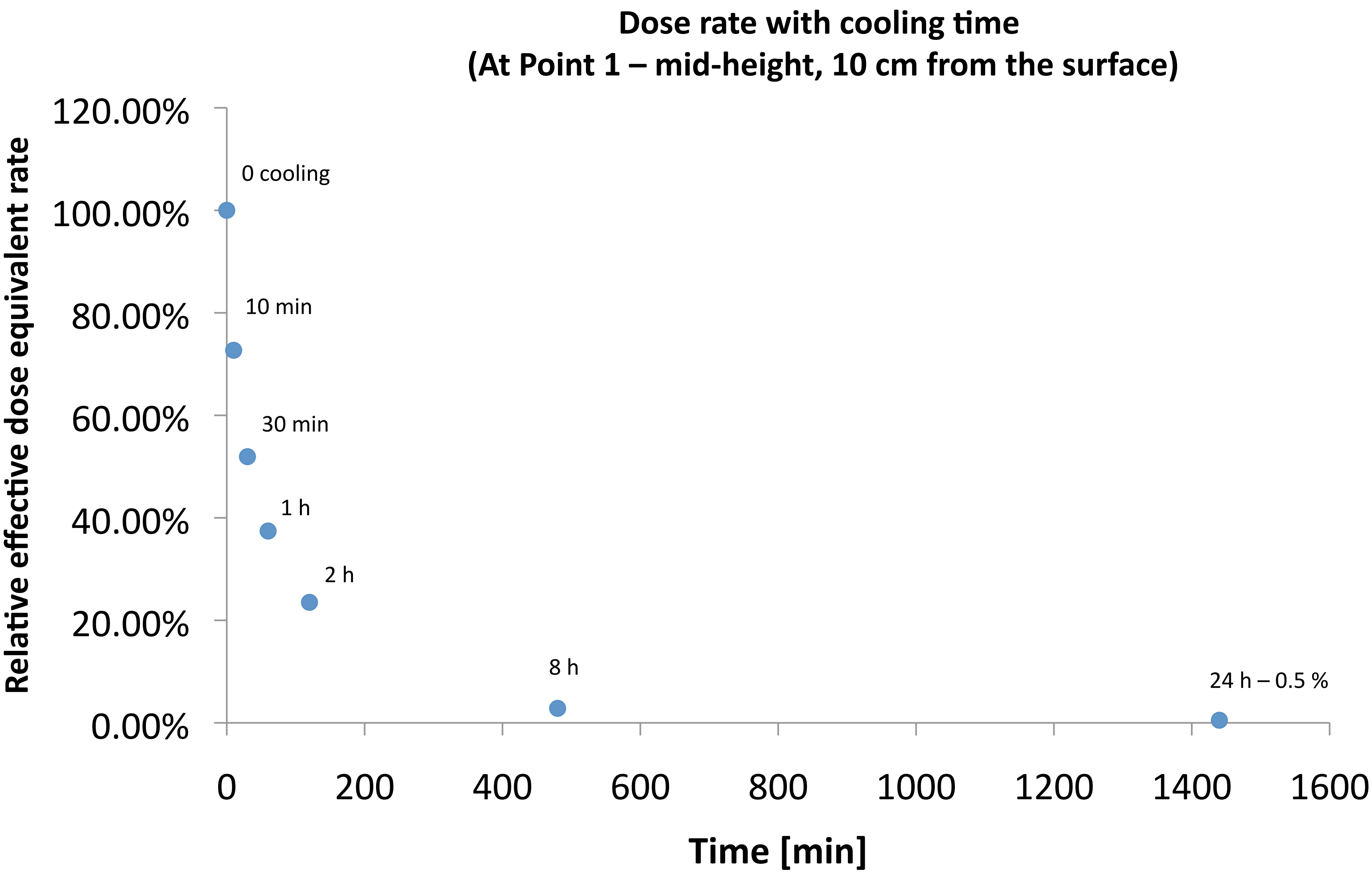
Radionuclide	Flow model saturation [Bq/g]	Activity for the Microshield calculation [Bq]	Decay radiation
^{3}H	8.78E+01		Beta(-)
^{7}Be	1.61E+01	1.61E+07	Epsilon, Gamma
^{10}Be	1.16E+01		Beta(-)
^{11}C	4.78E+01	4.78E+07	Epsilon, Beta(+)
^{14}C	2.43E+01		Beta(-)
^{18}F	7.51E+01	7.51E+07	Epsilon, Beta(+)
^{13}N	5.48E+00	5.48E+06	Epsilon, Beta(+)
^{14}O	1.14E+00		Beta(+) [71s]
^{15}O	2.51E+01	2.51E+07	Epsilon, Beta(+)
^{19}O	1.33E+02		Beta(-), Gamma [27s]



Effective dose equivalent rate at 6 positions around the tank [µSv/h]
19.2
8.4
4.1
1.5
9.6
1.2
cm
100
0
10
50
100
200
cm



Effective dose equivalent rate [µSv/h]
25.00
20.00
15.00
10.00
5.00
0.00
0
50
100
150
200
250
Distance from the tank [cm]
Mid-height
Bottom


Dose rate with cooling time
(At Point 1 – mid-height, 10 cm from the surface)
Relative effective dose equivalent rate
120.00%
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
0 cooling
10 min
30 min
1 h
2 h
8 h
24 h – 0.5 %
0
200
400
600
800
1000
1200
1400
1600
Time [min]

If the activated fluorocarbon spills out and evaporates, the a possibility of inhaling radionuclides cannot be excluded.

INHALATION EXPOSURE IN CASE OF A FLUOROCARBON LEAK

Committed inhalation dose in case of a leak – Source terms

	Swiss conversion coeffisients [Sv/Bq]	Activity (Flow model saturation) [Bq/g]	Activity (Static model, 5 years of irradiation) [Bq/g]	Dose per gram of fluorocarbon [Sv/g]
^{3}H	4.1E-11	8.78E+01		3.60E-09
^{7}Be	4.6E-11	1.61E+01		7.41E-10
^{10}Be	1.9E-08	1.16E+01	1.27E-04	2.41E-12
^{11}C	3.2E-12	4.78E+01		1.53E-10
^{14}C	5.8E-10	2.43E+01	5.43E-02	3.15E-11
^{18}F	9.3E-11	7.51E+01		6.98E-09
^{13}N	NA	5.48E+00		
^{14}O	NA	1.14E+00		
^{15}O	NA	2.51E+01		
^{19}O	NA	1.33E+02		

Committed inhalation dose in case of a leak – Results

	Committed dose per 1 gram of inhaled fuorocarbon [Sv/g]
Radioactivity at saturation (except for ^{10}Be and ^{14}C) – model for a leak that occurs while the beam is on	1.15E-08
A leak that occurs during shutdown after the decay of ^{11}C and ^{18}F	4.37E-09

- How much fluorocarbon can a person breath in?
- Breathing rate: 1.2 m^3/h
- Fraction of fluorocarbon in the air: 1%
- Results in 100 g of inhaled fluorocarbon.
- The dose committed in one hour is 1.15 µSv if leak occurs while the beam is on and 0.44 µSv if it occurs during shutdown.

Conclusion

- The radiological aspects have to be taken into account in relation to the cooling system. The estimated dose rates and effective doses are of the same order of magnitude as important reference values at CERN. For example, the ambient dose equivalent rate of 15µSvh^{-1} is used in the CERN's area classification system as the boundary between the supervised radiation area and the simple controlled radiation area. Regarding internal exposure, CERN's guidelines operate with a reference level of 1 µSv per hour of stay.
- The associated radiological risk is not alarming but it has to be properly managed in order to optimize the radiological protection.
- In order to do that:
  1. Let's all keep the issue in mind
     - When planning and performing intervention on the system
     - When planning modifications of the system (moving the tank, changing the coolant, etc.)
     - …
  2. Can you help us identify the possible maintenance and accident scenarios
  3. Can we make a guess on what fraction of radionuclides will stay in the fluorocarbon and what fraction will stick to the walls of the system and to the filters?
  4. Can we make a guess on what fraction of radionucldies will evaporate into the air in case of a spill and how much fluorocarbon can a person breath in?
  5. …