DRAFT
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ACTIVATION OF ARGON

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1) Liquid Argon (LAr) is used in the ATLAS Calorimeters. There are one Barrel and two End Cap calorimeters. Total mass of LAr assumed for strength analysis is 52 t for two End Caps and 62 t for the Barrel. The mass seems to be conservative.

2) Calorimeter is situated in the area with high radiation level and, consequently, its materials may be activated to a significant level during LHC operation. The aim of this note is to report on Argon activity levels estimated within the framework of the ISTC #1800 Partner Project.

3) Some estimation of activity induced in LAr by neutrons one may find in TDR LIQUID ARGON CALORIMETER (p.468, Table 11-1), where total equilibrium activity of ^{41}Ar in Barrel and separate elements of End Cap had been reported. The previous results together with results from the present study are given in Table 1. There is a perfect agreement for total equilibrium activity[1]. in Barrel. It is difficult to understand from the TDR if the total activity in End Cap detectors refers to a single End Cap or to both End Caps. New results are given for a single End Cap. Again, one can see a rather satisfactory agreement in EMEC and HEC. Newly calculated activity in FCAL is 2-3 times above TDR values, though FCAL produce only few percents into the total activity of End Cap.

Table 1

Equilibrium activity of Ar-41 induced by neutrons in the calorimeter, GBq

	Barrel	EMEC	HEC	FCAL1	FCAL2+3
TDR LAR, Table 11-1	49	98	11	1.1	0.5
New Results	42	107(*	9.2(*	1.8(*	1.7(*
(* Activity per single END CAP					

4) Geometry and LAr volume fraction in the Barrel and End Cap calorimeters, which were used in this estimation, are given in Tables 2-3. The data was adopted from GCOLOUR geometry data files. The geometry files and hadrons fluxes had been produced by Mike Supe.

One can see from the last rows of Tables 2-3 that total masses of LAr in both Barrel and End Caps are well below the values reported in the TDR (see 1). It is due to either disregard of LAr in pipes and overflow vessels outside the Calorimeter or overestimation of LAr mass in the TDR.

5) Total activity in the Barrel and End Cap was calculated for exposure time T=100 days and 10 years and various cooling times. Results are given in Tables 4-7. Activation induced by low energy neutrons and high-energy hadrons (neutrons, protons, and Pi$^+$, Pi$^-$ mesons) are given separately. Activity of a separate radionuclide — product of activation reaction or decay of the product— is given in Bq per half Barrel or per one End Cap. Total activity is given in Bq per Barrel or per two End Caps. Grand Total is sum of total activities induced by low energy neutrons and high-energy hadrons.

6) Specific kerma-equivalent was calculated from total activities of radionuclides A, their gamma-factors Γ (see table 8), and mass of LAr per End Cap or Barrel:

[1] Equilibrium activity is reached in steady flux at exposure time T>> Half Life of the radionuclide and cooling time t=0.

$$k_{e,m} = \frac{\sum_i A_i \Gamma_i}{m}.$$

Mass of LAr was taken from Tables 2-3. So that, this estimations for specific kerma-equivalent will be conservative as the mass do not include LAr from overflow vessels. Contribution of the vessels into the total activity will be negligible, but LAr in the vessels is to decrease specific activity (and specific kerma-equivalent) due to dilution. As a result specific values may be overestimated by factor of 1.4 in End Cap and by 1.5 in the Barrel.

Table 8

Gamma-factors of some important radionuclides

Radionuclide(*	^{22}Na	^{24}Na	^{28}Mg	^{28}Al	^{38}S	^{38}Cl	^{41}Ar
Γ, 10^{-18} Gy.m^2/(s.Bq)	78.2	120	50.2	55	51.3	43.5	43.2
(* Other radionuclides from tables 4-7 do not emit gamma-radiation							

7) Dose rate on surface of half-infinite source uniformly contaminated with radionuclides was estimated as:

$$\dot{H} = \frac{2\pi\, k_{e,m}}{\mu_{en,m}^{AR}} w 10^4 \cdot 3600,$$

where,

$\dot{H}$ - equivalent dose rate, Sv/h

$k_{e,m}$ - specific kerma-equivalent, (Gy.m^2)/(s.g),

$\mu_{en,m}^{AR}$ = 0.0254, cm^2/g - energy mass attenuation coefficient in Ar for energy of gamma rays 1 MeV.

w=1 - tissue weighing factor, Sv/Gy.

Surface dose rate against time is given on Fig. 1-2. It is interesting to note that dose rate induced by neutrons (^{41}Ar) is rather high and will dominate within first 15 hours after shutdown. After t=1 day, hadron activation (^{24}Na and ^{22}Na) will dominate.

8) While maintenance period, LAr is to be pored from the Calorimeter to storage tanks. Two storage tanks are envisaged— one for LAr from the Barrel and one for two End Caps— 50 m^3 each. The dose rate from Tables 4-7 may be taken as a conservative estimation of dose rate at surface of a storage tank. To do more correct dose estimation it is necessary to define access scenarios to the tanks. Namely geometry parameters R, H, L, and d are needed. In addition, a more realistic estimation for total mass of LAr in Barrel and End Cap is desirable.

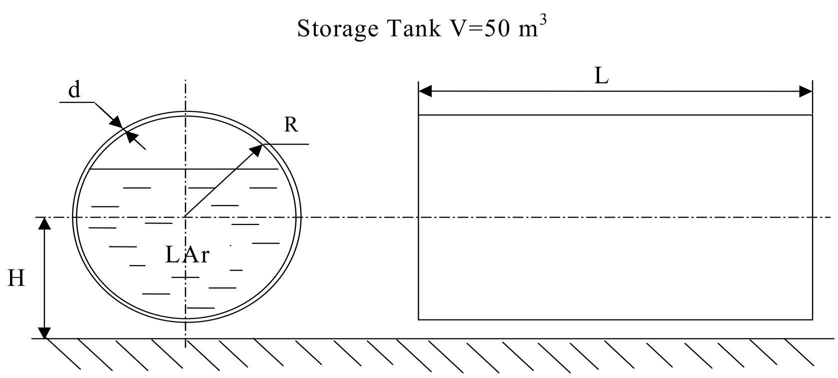

Fig.3. Access scenario to the LAr storage tanks.

Table 2

Geometry and LAr content in Barrel EM Calorimeter

##	Structure	Zmin	Zmax	Rmin	Rmax	Volume, m3	LAr vol. frac	LAr Mass, t
1	Preshower detector	0	300.8	140.5	143.6	0.832	0.037	0.043
2	Liquid argon in front of preshower	0	300.8	138.5	140.5	0.527	1	0.738
3	Middle Acordion Volume	0	134.1	151	197.9	6.890	0.592	5.711
4 5 6 7	North accordion Volume Wedge	134.1 145 155 165	145 155 165 175.8	157.2 168.9 180.1 191.5	197.9 197.9 197.9 197.9	0.495 0.334 0.211 0.085	0.592 0.592 0.592 0.592	0.410 0.277 0.175 0.070
8 9 10 11	North accordion Volume Wedge	134.1 145 155 165	145 155 165 175.8	151 151 151 151	157.2 168.9 180.1 191.5	0.065 0.180 0.303 0.470	0.649 0.649 0.649 0.649	0.059 0.163 0.275 0.427
12	North Accordion Volume Cylinder	175.8	300.8	151	197.9	6.423	0.649	5.836
13	North Accordion End Volume	300.8	315	151	197.9	0.730	0.649	0.663
14	Accordion Front	0	300.8	144	151	1.950	0.159	0.434
15	Accordion Exit	0	315	197.9	214	6.559	0.425	3.903
16	Liquid at the end of EM Accordion	315	326.7	156.6	219	0.861	1	1.205
	Total x 2					53.83(*)		40.78

(*) toltal volume of cold vessel is 58 m3 (LAr TDR, p.67)

Table 3

Geometry and LAR content in End Cap Calorimeters

##	Structure	Zmin	Zmax	Rmin	Rmax	Volume, m^3	LAr vol. frac	LAr Mass, t
1	EM Inner Volume	367.7	385	30.7	47	0.069	0.599	0.058
2		385	402	32.1	56.2	0.114	0.599	0.095
3		402	419.5	33.5	64.9	0.170	0.599	0.142
4	EM Outer Volume	367.7	385	47	208.9	2.251	0.621	1.957
5		385	402	56.2	208.9	2.161	0.621	1.879
6		402	419.5	64.9	208.9	2.167	0.621	1.884
7	HEC 1A	426.5	456.7	37	208.9	4.008	0.242	1.358
8	HEC 1B	456.7	510.9	47.3	208.9	7.046	0.254	2.506
9	HEC 2	512	610.8	47.3	208.9	12.844	0.141	2.535
10	Liquid AR outside support tube	476.5	635	46.5	47.3	0.037	1	0.052
11	Cable fill in pocket at back of cylindrical transition	623	644.5	49.5	59	0.070	0.833	0.081
12	Liquid argon and cables in front of EMEC	361.2	367.7	30	208.9	0.872	0.833	1.017
13	Liquid argon and cables outside hadronic modules	361.2	644.5	208.9	212.4	1.312	0.833	1.530
14	Liquid argon and cables at rear of HEC2	610.8	627.5	69	208.9	2.039	0.833	2.378
15	Liquid argon and cables at rear of EMEC	419.5	426.5	37	208.9	0.929	0.833	1.084
16	Liquid argon and cables at rear of first hadronic compartment	510.9	512	47.3	208.9	0.143	0.833	0.167
17	FC EM (FCAL1)	466.85	532	7.2	45	0.404	0.0772	0.044
18	Liquid argon and cables outside FCAL	480.5	658.3	45	45.7	0.035	0.833	0.041
19	Liquid argon and cables behind EM	532	532.5	7.9	45	0.003	0.833	0.004
20	FC H1 (FCAL2)	532.5	577.65	7.9	45	0.278	0.162	0.063
21	Liquid argon and cables at back of FC H1	577.65	580.15	8.6	45	0.015	0.833	0.018
22	FC H2 (FCAL3)	580.15	625.3	8.6	45	0.277	0.191	0.074
23	Liquid argon and cables at back of FC H2	625.3	627.8	9.5	45	0.015	0.833	0.018
	Total x 2					74.52(*)		37.97

(*) toltal volume of cold vessels 80 m3 (LAr TDR, p.68),

Table 4

Activation of Argon in Barrel Calorimeter at T=100 days

Reaction (Decay)	Half Life	Coolling time, t										
		0	20 M	1H	3H	10H	1D	3D	10D	30D	100D	1Y
		Neutrons										
Ar-36 (n,g) Ar-37	34.8 D	4.54E+08	4.54E+08	4.54E+08	4.53E+08	4.50E+08	4.45E+08	4.28E+08	3.72E+08	2.50E+08	6.20E+07	3.17E+05
Ar-38 (n,g) Ar-39	269 Y	1.19E+04	1.19E+04	1.19E+04	1.19E+04	1.19E+04	1.19E+04	1.19E+04	1.19E+04	1.19E+04	1.19E+04	1.18E+04
Ar-40 (n,g) Ar-41	1.83 H	2.11E+10	1.86E+10	1.44E+10	6.77E+09	4.78E+08	2.38E+06					
Total x 2, Bq		4.31E+10	3.81E+10	2.98E+10	1.44E+10	1.86E+09	8.95E+08	8.56E+08	7.44E+08	5.00E+08	1.24E+08	6.57E+05
		Hadrons										
Ar-40 (x,S) Na-24	14.95 H	1.50E+07	1.47E+07	1.43E+07	1.30E+07	9.40E+06	4.91E+06	5.31E+05				
Ar-40 (x,S) Na-22	2.61 Y	1.94E+05	1.94E+05	1.94E+05	1.94E+05	1.94E+05	1.94E+05	1.94E+05	1.93E+05	1.90E+05	1.80E+05	1.49E+05
K-37 β^+ Ar-37	35.04 D	2.82E+05	2.82E+05	2.82E+05	2.81E+05	2.80E+05	2.77E+05	2.66E+05	2.31E+05	1.56E+05	3.90E+04	
Ar-40 (x,S) Ar-37	35.04 D	3.84E+08	3.84E+08	3.84E+08	3.83E+08	3.81E+08	3.77E+08	3.62E+08	3.15E+08	2.12E+08	5.32E+07	2.82E+05
Ar-40 (x,S) Cl-39	55.6 M	8.11E+07	6.32E+07	3.84E+07	8.60E+06	4.58E+04						
Cl-39 β^- Ar-39	269 Y	5.72E+04	5.72E+04	5.72E+04	5.72E+04	5.72E+04	5.72E+04	5.72E+04	5.72E+04	5.72E+04	5.72E+04	5.71E+04
Ar-40 (x,S) S-38	2.84 H	5.93E+04	5.46E+04	4.64E+04								
S-38 β^- Cl-38	37.2 M	5.93E+04	5.85E+04	5.40E+04	1.27E+02							
Ar-40 (x,S) S-35	87.5 D	3.50E+07	3.50E+07	3.50E+07	3.49E+07	3.49E+07	3.47E+07	3.42E+07	3.23E+07	2.76E+07	1.58E+07	1.94E+06
P-35 β^- S-35	87.5 D	9.56E+05	9.56E+05	9.56E+05	9.55E+05	9.53E+05	9.49E+05	9.34E+05	8.83E+05	7.54E+05	4.33E+05	5.31E+04
Ar-40 (x,S) P-33	25.3 D	6.83E+07	6.82E+07	6.82E+07	6.80E+07	6.75E+07	6.64E+07	6.29E+07	5.19E+07	3.01E+07	4.43E+06	3.16E+03
Ar-40 (x,S) P-32	14.3 D	1.55E+08	1.55E+08	1.55E+08	1.54E+08	1.52E+08	1.48E+08	1.34E+08	9.53E+07	3.61E+07	1.20E+06	
Si-33 β^- P-33	25.3 D	7.61E+04	7.61E+04	7.60E+04	7.58E+04	7.52E+04	7.40E+04	7.01E+04	5.79E+04	3.35E+04		
Ar-40 (x,S) Si-31	2.62 H	1.42E+07	1.30E+07	1.09E+07	6.44E+06	1.01E+06						
Al-32 β^-, β^- P-32	14.3 D	5.53E+04	5.52E+04	5.51E+04	5.49E+04	5.40E+04	5.20E+04	4.66E+04	2.53E+04			
Al-31 β^- Si-31	2.62 H	4.49E+04	3.48E+04	1.08E+04								
Ar-40 (x,S) Mg-28	20.9 H	1.51E+05	1.49E+05	1.46E+05	1.37E+05	1.08E+05	6.81E+04					
Mg-28 β^- Al-28	2.24 M	1.51E+05	1.49E+05	1.46E+05	1.37E+05	1.09E+05	6.82E+04					
Ar-40 (x,S) Si-32	162 Y											2.41E+03
Si-32 β^- P-32	14.3 D											2.41E+03
Total x 2, Bq		1.57E+09	1.53E+09	1.48E+09	1.40E+09	1.36E+09	1.33E+09	1.25E+09	1.05E+09	6.53E+08	1.67E+08	8.19E+06
Grand Total, GBq		44.7	39.7	31.3	15.9	3.26	2.27	2.15	1.83	1.18	0.30	0.009
$K_{e,m}$, Gy.m^2/(s.g)		4.49E-14	3.95E-14	3.06E-14	1.43E-14	1.04E-15	3.48E-17	3.92E-18	7.35E-19	7.35E-19	6.86E-19	5.88E-19
Dose, 10^{-6} Sv/h		441	387	300	141	10	0.34	0.039	0.007	0.007	0.007	0.006

Table 5

Activation of Argon in Barrel Calorimeter at T=10 years

Reaction (Decay)	Half Life	Coolling time, t										
		0	20 M	1H	3H	10H	1D	3D	10D	30D	100D	1Y
		Neutrons										
Ar-36 (n,g) Ar-37	34.8 D	4.79E+08	4.79E+08	4.79E+08	4.78E+08	4.75E+08	4.70E+08	4.52E+08	3.93E+08	2.64E+08	6.54E+07	3.34E+05
Ar-38 (n,g) Ar-39	269 Y	1.43E+05	1.43E+05	1.43E+05	1.43E+05	1.43E+05	1.43E+05	1.43E+05	1.43E+05	1.43E+05	1.43E+05	1.42E+05
Ar-40 (n,g) Ar-41	1.83 H	2.11E+10	1.86E+10	1.44E+10	6.77E+09	4.78E+08	2.38E+06					
Total x 2, Bq		4.31E+10	3.81E+10	2.98E+10	1.45E+10	1.91E+09	9.45E+08	9.03E+08	7.86E+08	5.28E+08	1.31E+08	9.53E+05
		Hadrons										
Ar-40 (x,S) Na-24	14.95 H	1.50E+07	1.47E+07	1.43E+07	1.30E+07	9.40E+06	4.91E+06	5.31E+05				
Ar-40 (x,S) Na-22	2.61 Y	9.04E+05	9.04E+05	9.04E+05	9.04E+05	9.04E+05	9.04E+05	9.02E+05	8.98E+05	8.85E+05	8.41E+05	6.93E+05
K-37 β^+ Ar-37	35.04 D	2.97E+05	2.97E+05	2.97E+05	2.96E+05	2.95E+05	2.91E+05	2.80E+05	2.44E+05	1.64E+05	2.44E+05	
Ar-40 (x,S) Ar-37	35.04 D	4.06E+08	4.06E+08	4.05E+08	4.05E+08	4.02E+08	3.98E+08	3.82E+08	3.33E+08	2.24E+08	5.61E+07	2.97E+05
Ar-40 (x,S) Cl-39	55.6 M	8.11E+07	6.32E+07	3.84E+07	8.60E+06	4.58E+04						
Cl-39 β^- Ar-39	269 Y	6.79E+05	6.79E+05	6.79E+05	6.79E+05	6.79E+05	6.79E+05	6.79E+05	6.79E+05	6.79E+05	6.79E+05	6.77E+05
Ar-40 (x,S) S-38	2.84 H	5.93E+04	5.46E+04	4.64E+04								
Ar-40 (x,S) S-35	87.5 D	4.15E+07	4.15E+07	4.15E+07	4.14E+07	4.14E+07	4.11E+07	4.05E+07	3.83E+07	3.27E+07	1.88E+07	2.30E+06
P-35 β^- S-35	87.5 D	1.14E+06	1.14E+06	1.14E+06	1.13E+06	1.13E+06	1.13E+06	1.11E+06	1.05E+06	8.95E+05	1.05E+06	6.30E+04
Ar-40 (x,S) P-33	25.3 D	7.04E+07	7.04E+07	7.03E+07	7.01E+07	6.96E+07	6.85E+07	6.48E+07	5.35E+07	3.10E+07	4.57E+06	3.25E+03
Ar-40 (x,S) P-32	14.3 D	1.55E+08	1.55E+08	1.55E+08	1.54E+08	1.52E+08	1.48E+08	1.34E+08	9.53E+07	3.61E+07	1.20E+06	
Ar-40 (x,S) Si-31	2.62 H	1.42E+07	1.30E+07	1.09E+07	6.44E+06	1.01E+06						
Ar-40 (x,S) Mg-28	20.9 H	1.51E+05	1.49E+05	1.46E+05	1.37E+05	1.08E+05	6.81E+04					
Mg-28 β^- Al-28	2.24 M	1.51E+05	1.49E+05	1.46E+05	1.37E+05	1.09E+05	6.82E+04					
Ar-40 (x,S) Si-32	162 Y									2.88E+04	2.88E+04	2.87E+04
Si-32 β^- P-32	14.3 D									2.88E+04	2.88E+04	2.87E+04
Total x 2, Bq		1.57E+09	1.53E+09	1.48E+09	1.40E+09	1.36E+09	1.33E+09	1.25E+09	1.05E+09	6.53E+08	1.67E+08	8.19E+06
Grand Total, GBq		44.7	39.7	31.3	15.9	3.26	2.27	2.15	1.83	1.18	0.30	0.009
$K_{e,m}$, Gy.m^2/(s.g)		4.49E-14	3.95E-14	3.06E-14	1.43E-14	1.04E-15	3.73E-17	6.86E-18	3.43E-18	3.38E-18	3.19E-18	2.65E-18
Dose, 10^{-6} Sv/h		441	387	300	141	10	0.37	0.067	0.034	0.033	0.031	0.026

Table 6

Activation of Argon in End Cap Calorimeter at T=100 days

Reaction (Decay)	Half Life	Coolling time, t										
		0	20 M	1H	3H	10H	1D	3D	10D	30D	100D	1Y
		Neutrons										
Ar-36 (n,g) Ar-37	34.8 D	3.11E+09	3.11E+09	3.11E+09	3.10E+09	3.09E+09	3.05E+09	2.93E+09	2.55E+09	1.71E+09	4.25E+08	2.17E+06
Ar-38 (n,g) Ar-39	269 Y	8.09E+04	8.09E+04	8.09E+04	8.09E+04	8.09E+04	8.09E+04	8.09E+04	8.09E+04	8.09E+04	8.09E+04	8.07E+04
Ar-40 (n,g) Ar-41	1.83 H	1.41E+11	1.24E+11	9.62E+10	4.51E+10	3.19E+09	1.59E+07					
Total x 2, Bq		2.87E+11	2.54E+11	1.99E+11	9.64E+10	1.25E+10	6.13E+09	5.86E+09	5.10E+09	3.42E+09	8.50E+08	4.50E+06
		Hadrons										
Ar-40 (x,S) Na-24	14.95 H	1.51E+08	1.49E+08	1.44E+08	1.32E+08	9.51E+07	4.97E+07	5.37E+06				
Ar-40 (x,S) Na-22	2.61 Y	3.33E+06	3.33E+06	3.33E+06	3.33E+06	3.33E+06	3.33E+06	3.33E+06	3.31E+06	3.26E+06	3.10E+06	2.56E+06
K-37 β^+ Ar-37	35.04 D	1.74E+06	1.74E+06	1.74E+06	1.73E+06	1.72E+06	1.70E+06	1.64E+06	1.43E+06	9.60E+05	2.41E+05	
Ar-40 (x,S) Ar-37	35.04 D	2.46E+09	2.46E+09	2.46E+09	2.45E+09	2.44E+09	2.41E+09	2.32E+09	2.02E+09	1.36E+09	3.40E+08	1.80E+06
Ar-40 (x,S) Cl-39	55.6 M	5.29E+08	4.12E+08	2.50E+08	5.61E+07	2.99E+05						
Cl-39 β^- Ar-39	269 Y	3.73E+05	3.73E+05	3.73E+05	3.73E+05	3.73E+05	3.73E+05	3.73E+05	3.73E+05	3.73E+05	3.73E+05	3.72E+05
Ar-40 (x,S) S-38	2.84 H	4.07E+05	3.75E+05	3.19E+05	1.19E+03							
S-38 β^- Cl-38	37.2 M	4.07E+05	4.02E+05	3.71E+05	1.15E+05							
Ar-40 (x,S) S-35	87.5 D	2.30E+08	2.30E+08	2.30E+08	2.30E+08	2.29E+08	2.28E+08	2.25E+08	2.12E+08	1.81E+08	1.04E+08	1.28E+07
P-35 β^- S-35	87.5 D	6.53E+06	6.53E+06	6.53E+06	6.52E+06	6.51E+06	6.48E+06	6.38E+06	6.03E+06	5.15E+06	2.96E+06	3.63E+05
Ar-40 (x,S) P-33	25.3 D	4.89E+08	4.89E+08	4.88E+08	4.87E+08	4.83E+08	4.76E+08	4.50E+08	3.72E+08	2.15E+08		
Ar-40 (x,S) P-32	14.3 D	1.14E+09	1.14E+09	1.14E+09	1.13E+09	1.12E+09	1.09E+09	9.85E+08	7.01E+08	2.65E+08		
Si-33 β^- P-33	25.3 D	5.60E+05	5.60E+05	5.60E+05	5.58E+05	5.54E+05	5.45E+05	5.16E+05	4.26E+05	2.47E+05	3.17E+07	2.26E+04
Ar-40 (x,S) Si-31	2.62 H	1.12E+08	1.03E+08	8.60E+07	5.07E+07	7.96E+06	2.70E+04					
Al-32 β^-, β^- P-32	14.3 D	5.03E+05	5.03E+05	5.02E+05	5.00E+05	4.93E+05	4.79E+05	4.35E+05	3.06E+05	3.85E+04		
Al-31 β^- Si-31	2.62 H	4.03E+05	3.68E+05	2.67E+05	2.50E+04							
Ar-40 (x,S) Mg-28	20.9 H	1.38E+06	1.36E+06	1.33E+06	1.25E+06	9.88E+05	6.21E+05	6.47E+03				
Mg-28 β^- Al-28	2.24 M	1.38E+06	1.36E+06	1.33E+06	1.25E+06	9.90E+05	6.22E+05	6.49E+03				
Ar-40 (x,S) Si-32	162 Y											1.84E+04
Si-32 β^- P-32	14.3 D											1.84E+04
Total x 2, Bq		1.02E+10	9.99E+09	9.61E+09	9.11E+09	8.77E+09	8.52E+09	7.99E+09	6.63E+09	4.06E+09	9.65E+08	3.58E+07
Grand Total, GBq		297	264	208	106	21.3	14.7	13.8	11.7	7.48	1.81	0.04
$K_{e,m}$, $Gy.m^2/(s.g)$		3.18E-13	2.81E-13	2.17E-13	1.01E-13	8.00E-15	3.67E-16	4.84E-17	1.37E-17	1.32E-17	1.26E-17	1.05E-17
Dose, 10^{-6} Sv/h		3123	2758	2134	992	79	3.6	0.48	0.13	0.13	0.12	0.10

Table 7

Activation of Argon in End Cap Calorimeter at T=10 years

Reaction (Decay)	Half Life	Coolling time, t										
		0	20 M	1H	3H	10H	1D	3D	10D	30D	100D	1Y
		Neutrons										
Ar-36 (n,g) Ar-37	34.8 D	3.28E+09	3.28E+09	3.28E+09	3.28E+09	3.26E+09	3.22E+09	3.09E+09	2.69E+09	1.81E+09	4.48E+08	2.29E+06
Ar-38 (n,g) Ar-39	269 Y	9.73E+05	9.73E+05	9.73E+05	9.73E+05	9.73E+05	9.73E+05	9.73E+05	9.73E+05	9.73E+05	9.73E+05	9.71E+05
Ar-40 (n,g) Ar-41	1.83 H	1.41E+11	1.24E+11	9.62E+10	4.51E+10	3.19E+09	1.59E+07					
Total x 2, Bq		2.88E+11	2.54E+11	1.99E+11	9.68E+10	1.29E+10	6.47E+09	6.19E+09	5.38E+09	3.62E+09	8.99E+08	6.52E+06
		Hadrons										
Ar-40 (x,S) Na-24	14.95 H	1.51E+08	1.49E+08	1.44E+08	1.32E+08	9.51E+07	4.97E+07	5.37E+06				
Ar-40 (x,S) Na-22	2.61 Y	1.56E+07	1.56E+07	1.56E+07	1.55E+07	1.55E+07	1.55E+07	1.55E+07	1.54E+07	1.52E+07	1.45E+07	1.19E+07
K-37 β^+ Ar-37	35.04 D	1.83E+06	1.83E+06	1.83E+06	1.83E+06	1.82E+06	1.80E+06	1.73E+06	1.50E+06	1.01E+06	2.53E+05	1.34E+03
Ar-40 (x,S) Ar-37	35.04 D	2.59E+09	2.59E+09	2.59E+09	2.59E+09	2.57E+09	2.54E+09	2.45E+09	2.13E+09	1.43E+09	3.59E+08	1.90E+06
Ar-40 (x,S) Cl-39	55.6 M	5.29E+08	4.12E+08	2.50E+08	5.61E+07	2.99E+05						
Cl-39 β^- Ar-39	269 Y	4.43E+06	4.43E+06	4.43E+06	4.43E+06	4.43E+06	4.43E+06	4.43E+06	4.42E+06	4.42E+06	4.42E+06	4.41E+06
Ar-40 (x,S) S-38	2.84 H	4.07E+05	3.75E+05	3.19E+05								
Ar-40 (x,S) S-35	87.5 D	2.68E+08	2.68E+08	2.68E+08	2.68E+08	2.67E+08	2.66E+08	2.62E+08	2.48E+08	2.11E+08	1.21E+08	1.49E+07
P-35 β^- S-35	87.5 D	7.75E+06	7.75E+06	7.75E+06	7.74E+06	7.73E+06	7.69E+06	7.57E+06	7.16E+06	6.11E+06	3.51E+06	4.30E+05
Ar-40 (x,S) P-33	25.3 D	5.04E+08	5.04E+08	5.04E+08	5.02E+08	4.98E+08	4.91E+08	4.64E+08	3.84E+08	2.22E+08	3.27E+07	2.33E+04
Ar-40 (x,S) P-32	14.3 D	1.14E+09	1.14E+09	1.14E+09	1.13E+09	1.11E+09	1.08E+09	9.81E+08	6.98E+08	2.64E+08	8.80E+06	
Si-33 β^- P-33	25.3 D	5.77E+05	5.77E+05	5.76E+05	5.75E+05	5.70E+05	5.61E+05	5.31E+05	4.39E+05	2.54E+05	3.74E+04	
Ar-40 (x,S) Si-32	162 Y	2.17E+05	2.17E+05	2.17E+05	2.17E+05	2.17E+05	2.17E+05	2.17E+05	2.17E+05	2.17E+05	2.17E+05	2.16E+05
Si-32 β^- P-32	14.3 D	2.17E+05	2.17E+05	2.17E+05	2.17E+05	2.17E+05	2.17E+05	2.17E+05	2.17E+05	2.17E+05	2.17E+05	2.16E+05
Ar-40 (x,S) Si-31	2.62 H	1.12E+08	1.03E+08	8.60E+07	5.07E+07	7.96E+06	1.86E+04					
Al-32 β^-, β^- P-32	14.3 D	5.07E+05	5.07E+05	5.06E+05	5.04E+05	4.97E+05	4.83E+05	4.38E+05	3.12E+05	1.18E+05		
Ar-40 (x,S) Mg-28	20.9 H	1.38E+06	1.36E+06	1.33E+06	1.25E+06	9.88E+05	6.21E+05	5.62E+03				
Mg-28 β^- Al-28	2.24 M	1.38E+06	1.36E+06	1.33E+06	1.25E+06	9.88E+05	6.21E+05	5.62E+03				
Total x 2, Bq		1.07E+10	1.04E+10	1.00E+10	9.52E+09	9.17E+09	8.93E+09	8.38E+09	6.98E+09	4.32E+09	1.09E+09	6.80E+07
Grand Total, GBq		298	265	209	106	22.1	15.4	14.6	12.4	7.93	1.99	0.07
$K_{e,m}$, Gy.m^2/(s.g)		3.18E-13	2.81E-13	2.17E-13	1.01E-13	8.05E-15	4.15E-16	1.00E-16	6.32E-17	6.32E-17	5.79E-17	4.89E-17
Dose, 10^{-6} Sv/h		3124	2759	2135	992	79	4.1	0.98	0.62	0.62	0.57	0.48

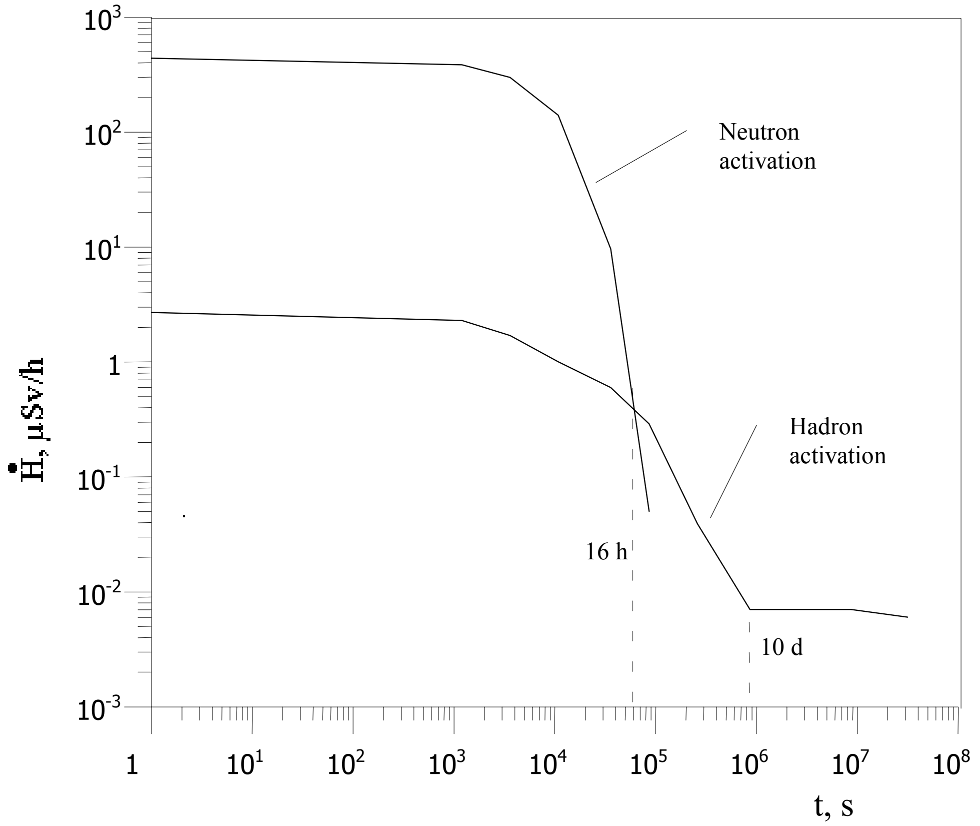

Fig.1 Equivalent dose rate at surface of a tank filled with argon from Barrel

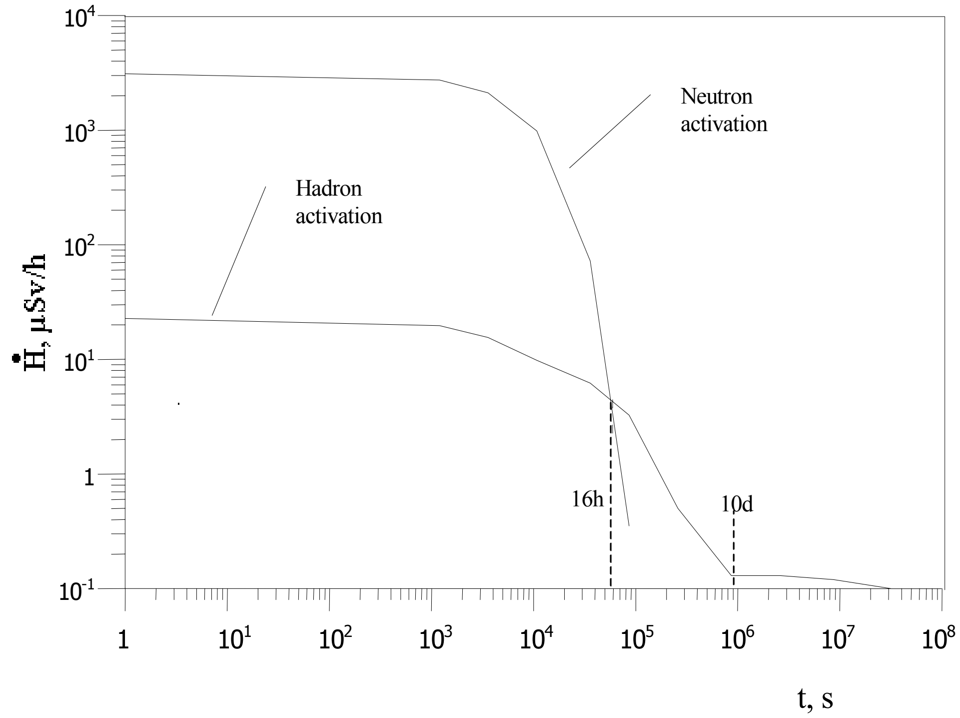

Fig.2. Equivalent dose rate at surface of a tank filled with argon from End Cap Calorimeter.

Estimation for H-3:

			Fe	Activity, Bq < Ar <	Al
Barrel[1]	T= 100d	t= 0h	2.55E+06	< ... <	3.15E+06
	T= 10y	t= 0h	2.40E+07	< ... <	2.96E+07
EC[2]	T= 100d	t= 0h	3.10E+07	< ... <	2.81E+07
	T= 10y	t= 0h	2.92E+08	< ... <	2.65E+08

(1) Activity is given for half-barrel
(2) Activity is given for a single End Cap

Estimation for Be-7:

			V	Activity, Bq < Ar <	Si
Barrel[1]	T= 100d	t= 0h	3.36E+06	< ... <	1.36E+07
	T= 10y	t= 0h	3.68E+06	< ... <	1.49E+07
EC[2]	T= 100d	t= 0h	5.90E+07	< ... <	1.64E+08
	T= 10y	t= 0h	6.46E+07	< ... <	1.80E+08

(1) Activity is given for half-barrel
(2) Activity is given for a single End Cap

Estimation was made based on cross-section data available for H-3 and Be-7 production in materials having closest atomic number to Ar.

Tritium cross-section in argon was estimated as following:

$$\Sigma(Ar\text{->}H^3) \leq \Sigma(Al\text{->}H^3)\ \{ \Sigma_{in}(Ca)/ \Sigma_{in}(Al) \}$$

$$\Sigma(Ar\text{->}H^3) \geq \Sigma(Fe\text{->}H^3)\ \{ \Sigma_{in}(Ca)/ \Sigma_{in}(Fe) \}$$

Be-7 cross-section in argon was estimated as following:

$$\Sigma(Ar\text{->}Be^7) \leq \Sigma(Si\text{->}Be^7)\ \{ \Sigma_{in}(Ca)/ \Sigma_{in}(Si) \}$$

$$\Sigma(Ar\text{->}Be^7) \geq \Sigma(V\text{->}Be^7)\ \{ \Sigma_{in}(Ca)/ \Sigma_{in}(V) \}$$

SIGMA(Al->H3){SIGMAin(Ca)/ SIGMAin(Al)}

means that the tritium production cross-section for aluminum SIGMA(Al->H3) was divided by the inelastic cross-section of aluminum SIGMAin(Al) and multiplied by the inelastic cross-section of calcium SIGMAin(Ca).

The general idea is that the production cross-section is a component of the inelastic cross-section and, consequently, there is some correlation between the two parameters.

So, SIGMAin(Ca)/SIGMAin(Al) is here assumed to be a normalization factor, which probably improves the estimation.

Why calcium? The inelastic cross-section data for argon is not known, but the inelastic cross-section data for calcium is available.

The inelastic cross-section shows a rather weak and regular dependence on atomic weight at high energy, so this substitution should not cause a big error.