Muon-induced background with LN_2 and LAr

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Prompt background

Electromagnetic and hadronic showers induced by muons, including inelastic neutron interactions (n,nγ)

→ **Substantially reduced** with anti-coincidence and dedicated vetos (**limited by veto efficiency only**)

	Nitrogen (counts/keV/kg/y)	Argon (counts/keV/kg/y)
Anti-coincidence only	$1.0 \cdot 10^{-3}$	$1.6 \cdot 10^{-3}$
Plastic veto (3 MeV, ε = 95%)	$8.8 \cdot 10^{-4}$	$1.4 \cdot 10^{-3}$
Cerenkov (120 MeV, ε = 95%)	$8 \cdot 10^{-5}$	$1.0 \cdot 10^{-4}$
Both vetos	$7 \cdot 10^{-5}$	$1.0 \cdot 10^{-4}$
Cerenkov with ε = 100%	$< 3 \cdot 10^{-5}$ (95% CL)	

Can be kept at the level of 10^{-4} counts/keV/kg/y or smaller. Further **improved** with **active LAr**

Delayed background

Muon-induced interactions can create long-lived (> ms) unstable isotopes in the set-up materials with **Q > $Q_{\beta\beta}$**

cannot be vetoed or shielded against

Isotopes in the crystals are the most relevant (detected with high-efficiency)

In crystals: ^{74}Ga, ^{75}Ga, ^{76}Ga, ^{68}Ge, ^{69}Ge, ^{77}Ge, ^{71}Zn

In cryoliquid: ^{13}N, ^{11}C, ^{12}B, ^{38}Cl, ^{39}Cl, ^{40}Cl

In water: ^{16}N, ^{14}O, ^{12}B, ^{6}He, ^{13}B

geometry-suppressed

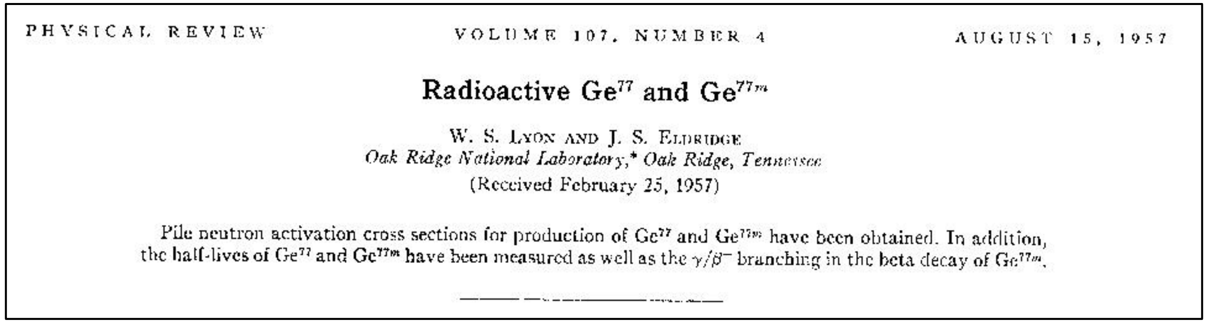
Red → isotopes > 10^{-6} counts/keV/kg/y

Most dangerous is **^{77}Ge** from **thermal neutrons**: no threshold, high cross section (0.14 b), high decay Q-value (2.7 MeV), **scales with enrichment**

Thermal neutron capture

Neutron capture in ^{76}Ge (0^+) can eventually populate (after IT) ^{77}Ge$_{g.s.}$($7/2^+$) or ^{77m}Ge ($1/2^-$, 159 keV)

^{77}Ge β-decays to ^{77}As ($T_{1/2}$ = 11.3 h, Q =2.7 MeV). ^{77m}Ge ($T_{1/2}$ = 52.9 s) can IT to ^{77}Ge$_{g.s.}$ (20%) or β-decay to ^{77}As (Q = 2.8 MeV)

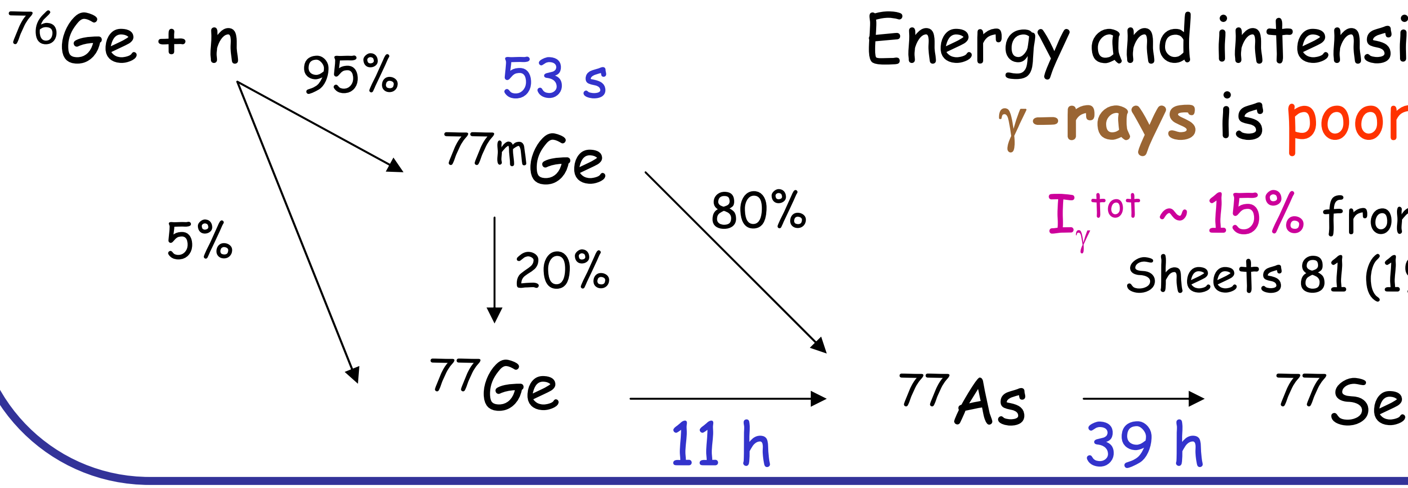

PHYSICAL REVIEW VOLUME 107, NUMBER 4 AUGUST 15, 1957

Radioactive Ge^{77} and Ge^{77m}

W. S. LYON AND J. S. ELDRIDGE
Oak Ridge National Laboratory, Oak Ridge, Tennessee*
(Received February 25, 1957)

Pile neutron activation cross sections for production of Ge^{77} and Ge^{77m} have been obtained. In addition, the half-lives of Ge^{77} and Ge^{77m} have been measured as well as the γ/β^- branching in the beta decay of Ge^{77m}.

Direct production of ^{77}Ge$_{g.s.}$: **5%**
Production through IT of ^{77m}Ge : **19%**



Energy and intensity of **prompt γ-rays** is poorly known

I_γ^{tot} ~ 15% from Nucl. Data Sheets 81 (1997) 417

Rejection strategies

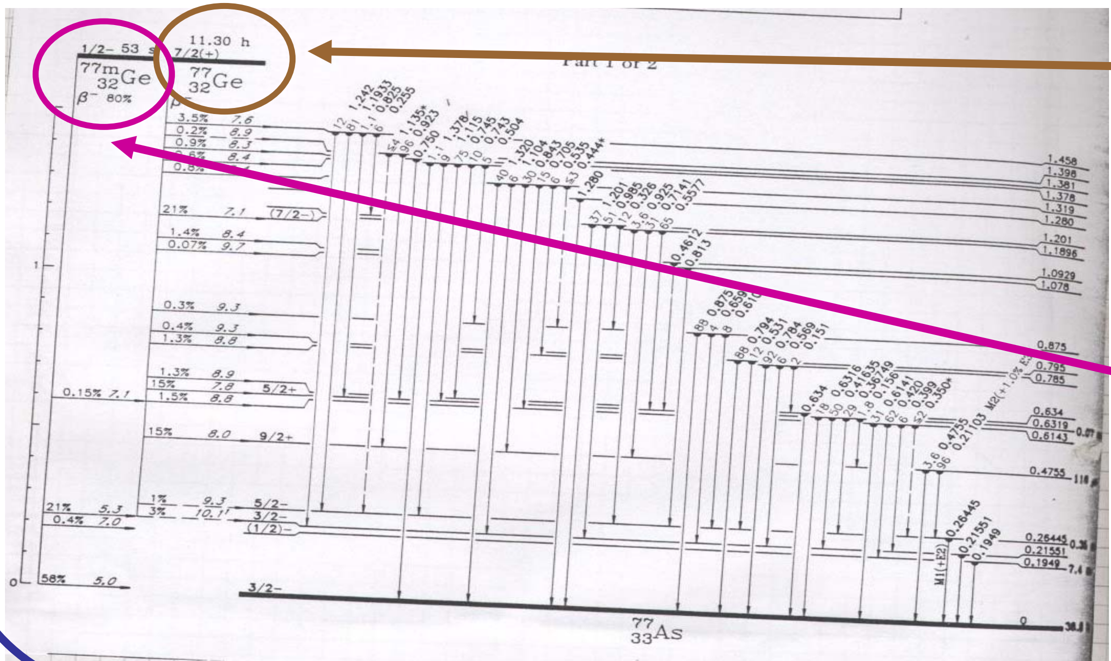
5% → $^{77}Ge \rightarrow {}^{77}As$ (11h) → (7/2^{+} → 3/2^{-} **a lot of γ-rays**)

76% → $^{77m}Ge \rightarrow {}^{77}As$ (53 s) → (1/2^{-} → 3/2^{-} ~ **no γ-rays**)

19% → $^{77m}Ge \rightarrow {}^{77}Ge$ (53 s) → ^{77}As (11h)

additional **delayed coincidence** with 159 keV γ-ray (?)

Worst scenario

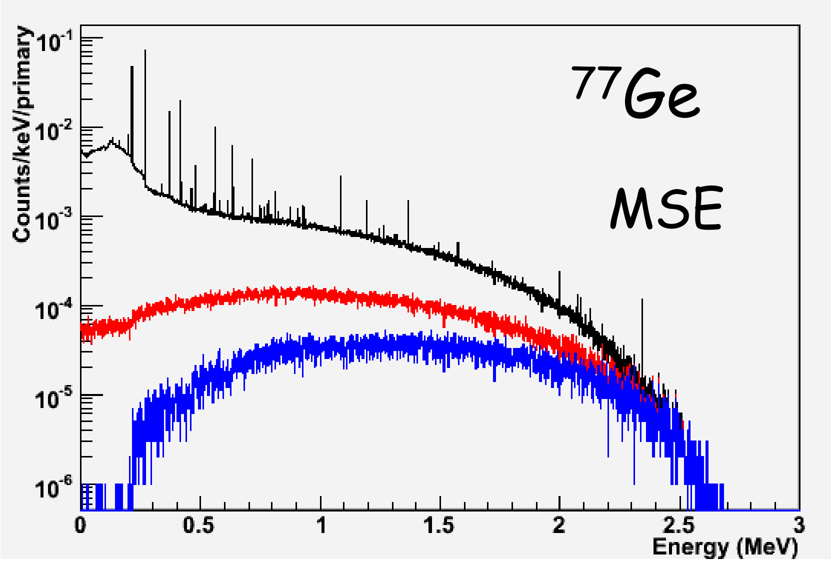


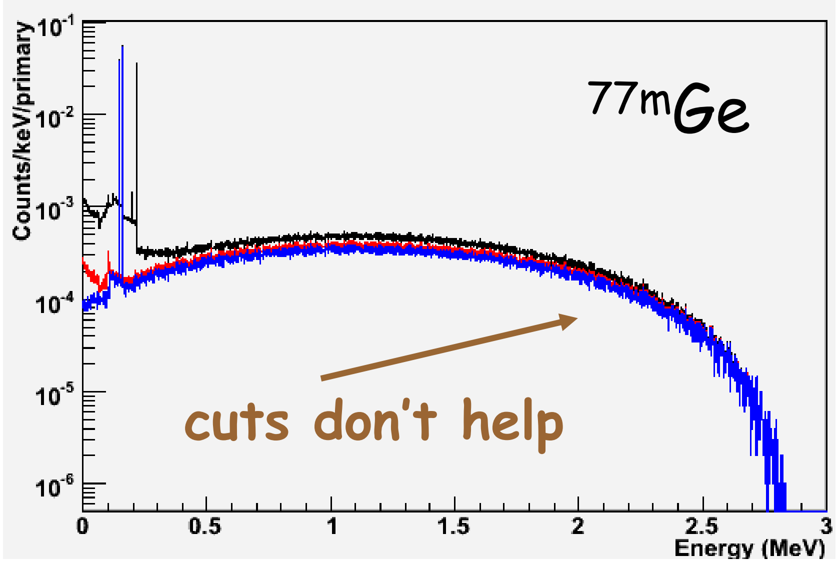
Complicated γ-ray decay → anticoincidence with crystal/segments and active veto are effective

Almost a pure β-decay (215 keV γ-ray with 25% BR) → SSE (!)

(no rejection!)

Background at $Q_{\beta\beta}$ (Phase II)





	^{77}Ge (counts/decay/keV)	^{77m}Ge (counts/decay/keV)
No cut	$8 \cdot 10^{-5}$	$2.1 \cdot 10^{-4}$
Segment coincidence	$3 \cdot 10^{-5}$	$1.9 \cdot 10^{-4}$
LAr veto (50 keV)	**$2 \cdot 10^{-5}$**	**$1.8 \cdot 10^{-4}$**

1 ev/kg/y → $2 \cdot 10^{-4}$ counts/keV/kg/y (**20%** of our total **background budget** for Phase II)

Introduce a dead time?

$T_{1/2}$ of ^{77m}Ge is 52.9 s

Add a **3-minute dead time** after each muon trigger?

Problem: the μ rate of the Cerenkov veto (above 120 MeV) is **2.5 counts/minute**

Feasible with a "rough" reconstruction of the muon track (direction) ? → to be studied.. ?

Notice: if the LAr is instrumented, μ trigger rate (above 50 MeV, inefficiency < 0.05%) is **0.22 counts/minute**

(total rate → kHz because of ^{39}Ar)

probably too large

^{77m}Ge is a very nasty background to deal with

Where do these neutrons come from?

Test with MaGe simulation: try to understand where neutrons (and γ-rays) do come from

constrain materials (e.g. thickness of Cu cryostat)

Divide the Gerda geometry in **"shells"** and run separately:

1) Only crystals + cryoliquid
2) Add the first Cu wall
3) Add the second Cu wall

...

n) Add the water tank

Shells **from inwards to outwards**. The "external" materials are **set to air**

Check the **differences from step to step**

Evaluate the **flux** of neutrons or γ-rays through a sphere (30 cm radius) containing the crystals

μ-induced neutron and γ fluxes

	Liquid Nitrogen		Liquid Argon	
	γ > 2 MeV ($\gamma/m^2/h$)	Neutrons ($n/m^2/h$)	γ > 2 MeV ($\gamma/m^2/h$)	Neutrons ($n/m^2/h$)
Only cryogenic liquid	0.039	0.006	2.2	0.45
+ first Cu wall (2 cm)	0.056	0.010	2.7	0.55
+ second Cu wall (2 cm)	0.062	0.011	2.3	0.57
+ third Cu wall (2 cm)	0.068	0.014	1.6	0.60
+ water and tank	1.34	0.180	2.5	1.43

dominated by **showering in water**

self-shielding

Thickness of Cu cryostat

Nitrogen → more than **92%** of the γ and neutron flux in the crystal due to showering in water (and steel)

↪ not very sensitive to the actual thickness of the Cu cryostat

γ flux: 2 times smaller, n flux: 8.5 times smaller

Argon:

neutron flux:

- 30% from Ar (unavoidable)
- **10% from Cu** (6 cm)
- 60% from water (90% of the low-energy n)

water thermalizes n, poorly absorbed by Ar

↪ thickness of Cu cryostat more relevant, not critical

$^{77}Ge/^{77m}Ge$ production rate

	Liquid Nitrogen (event/kg/y)	Liquid Argon (event/kg/y)
$^{77}Ge/^{77m}Ge$	0.04±0.03 (stat)	**0.57±0.06 (stat)**

(Total Cu: 6 cm)

20% from Ar, 10% from Cu, 70% from water

Systematics uncertainties dominated by **n-yield from μ**.
For Z=18 (Ar) Geant4 vs. Fluka better than 30-50%

Conservative margin: **1 event/kg/y** for Ar

background ~1-2 · 10^{-4} counts/keV/kg/y

Notice: the material of the infrastructure and the **Pb shielding** covering the neck was **NOT included**

→ rough estimate: **factor of 2 for 5 cm of Pb** in LAr

Conclusions

Prompt μ-induced background can be kept **under control**, provided the veto is efficient. LAr slightly worse, but the active shielding would help substantially

Isotope production (delayed background) is the most pernicious. **Relevant only for LAr**

Background rate from all isotopes (^{68}Ge, ^{69}Ge, ...) can be kept below 10^{-5} counts/keV/kg/y (possibly with segment coincidence and/or LAr veto), **except ^{77m}Ge**

^{77m}Ge gives mostly **single-site events**. Rejection strategies **NOT effective**. To be explored if it can be tagged with the μ (prompt γ?) and cut with dead-time

At present, it **limits the background** to $\sim 2 \cdot 10^{-4}$ counts/keV/kg/y **for LAr** (10^{-5} for LN → ok)

Backup