TENMAK TAGEP | PROJECT NO. 1881

KAHVELab Lithium Project and Future Plans

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CONTEXT

The PTAK 2 MeV proton beamline

KAHVELab is located on the Kandilli campus of Bogazici University and operates **PTAK** — Proton Testbeam at Kandilli. The injector consists of a microwave-discharge ion source, a permanent-magnet LEBT, a diagnostics box and an **800 MHz RFQ**. All elements were designed and manufactured in Turkiye.

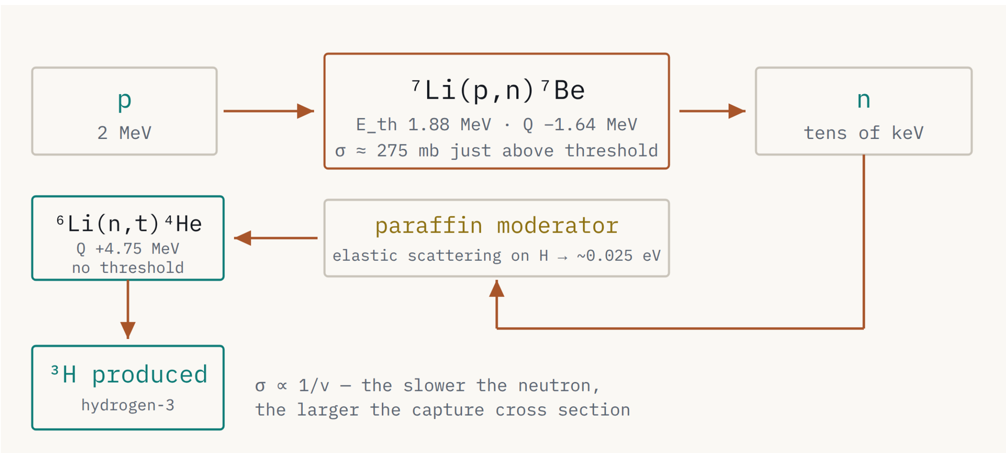
The output is a **2 MeV proton beam at 1 uA peak current** and low duty factor. Within TAGEP 1881, this beam is used to drive a compact neutron source, and the resulting neutrons are used to breed **^{3}H** in a second lithium target.

PHYSICAL BASIS

The two-stage reaction chain

The first reaction is endothermic and requires **1.88 MeV**. A 2 MeV beam therefore operates **120 keV above threshold**, where the emitted neutrons are soft and forward-peaked.

The second reaction is exothermic, has no threshold and has a positive Q-value of about **4.78 MeV**, meaning it occurs readily with thermal and slow neutrons rather than fast ones.



GEOMETRY

From a planar target to hemispherical shells

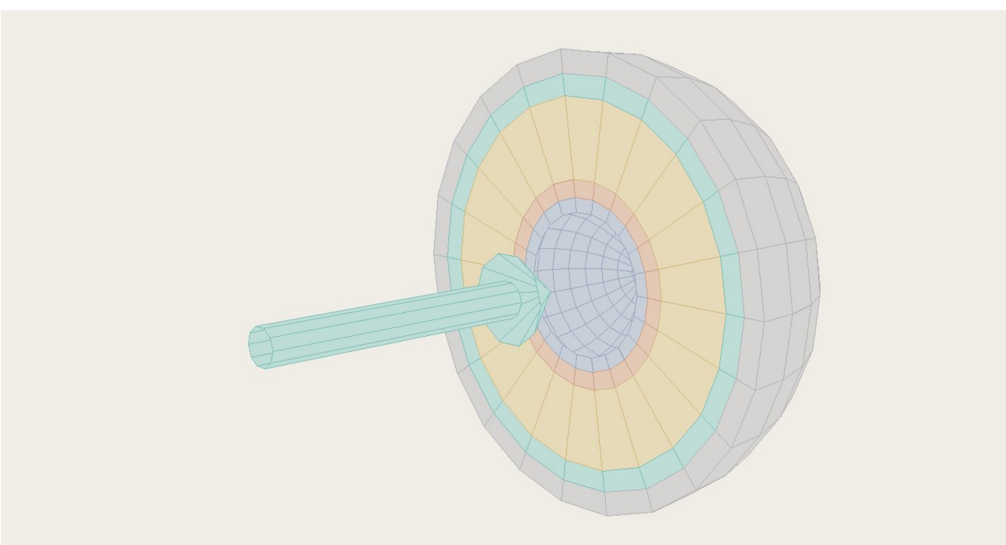
In the first report the target was a 20 um planar sheet. Two major losses were identified that a planar surface cannot fix.

Angular escape. Neutrons are emitted over a wide cone, whereas a flat plate subtends only the forward direction. A substantial fraction never reached the copper or the paraffin.

Lateral escape. Neutrons that did enter the paraffin drifted sideways and left through the side boundary before thermalisation was complete.

With hemispherical shells every emission angle is intercepted and lateral leakage is removed by construction.

Layer	Material	Dimension
0	vacuum channel	r = 0.5 cm
1	7Li	20 um
2	Cu (finned)	1 mm
3	paraffin	5 cm
4	6Li	100 um
5	steel frame	enclosure



PROJECT PLAN

Status of the work packages

Work package	Scope	Status
WP1	Target-1 (7Li) simulations	complete
WP2	Radiation simulations (FLUKA)	complete
WP3	Neutron thermalisation	complete
WP4	Target-2 (6Li) and shielding	complete
WP5	Beamline and proton diagnostics	80%
WP6	Radiation shielding structure	next
WP8	Target system engineering	next

Three major developments were not foreseen in the original plan: the target geometry was redesigned from planar plates to nested hemispherical shells, which required WP1 and WP2 to be repeated; the thermal analysis was transferred from FLUKA to ANSYS; and WP5 moved from design to hardware, with the quadrupole triplet, dipole and both steerers manufactured, measured and delivered.

WP2

7Li thickness and target lifetime

The thickness was scanned over **5–100 um** at 10^7 protons per point and assessed against the 1.88 MeV threshold. **20 um** was selected and confirmed at 10^8 protons. The 1 mm copper backing extinguishes the primary proton flux completely.

Burn-up was evaluated from the RESNUCLE nuclide-production card at 10^8 protons: **6.77×10^{-5}** nuclei per proton against **6.97×10^{19}** lithium atoms in the target, a consumption rate of 4.23×10^8 per second at 1 uA.

$\sim 1.3 \times 10^5$ yr

TIME TO HALF MASS

Shell volume 1.51×10^{-3} cm^3, density 0.534 g/cm3, mass 8.04×10^{-4} g. With the 2% duty factor included, half-consumption occurs at 4.12×10^{12} s. Burn-up is therefore not a design constraint; target life will be limited by surface oxidation and thermal cycling.

WP2

Neutron energy spectrum: shell versus plate

The neutron flux was scored with USRBDX at 10^9 primaries and a Landau function was fitted in Python to extract the most probable value.

Geometry	Most probable value
hemispherical shell	40.82 +/- 0.44 keV
planar sheet	49.72 +/- 0.41 keV

Same material, same nominal thickness, about **9 keV apart**. No single cause has been confirmed; the discrepancy is reported openly and remains under investigation.

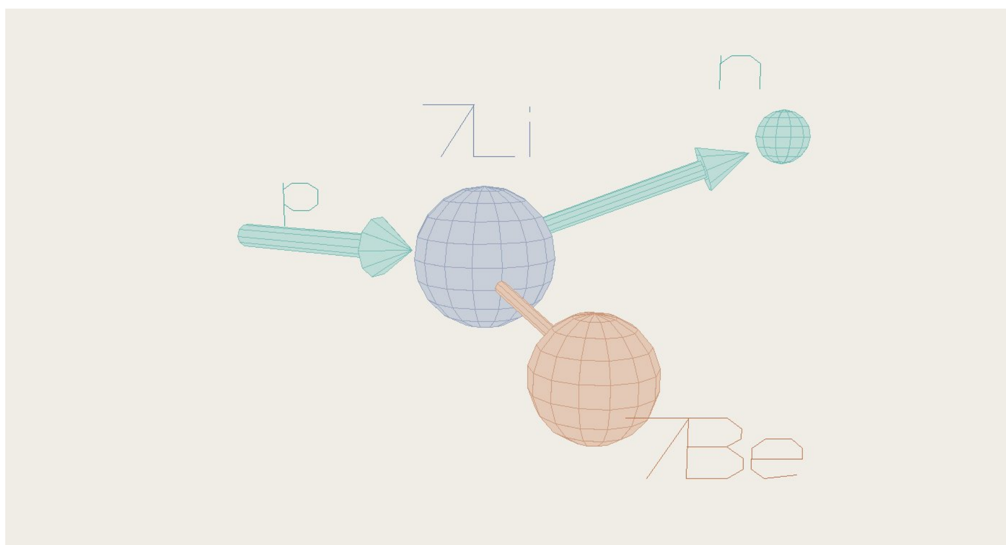
WP2

7Be production in the target

The ^{7}Li(p,n)^{7}Be reaction produces neutrons and simultaneously leaves beryllium-7 in the target. ^{7}Be has a **53-day half-life**, emits a **477 keV gamma**, and beryllium is chemically toxic.

Quantity	Value
7Be per primary proton	2.30e-05
continuous rate at 1 uA	1.44e+08 /s
actual rate at 2% duty factor	2.87e+06 /s

Scored with RESNUCLEI. The activity is modest, but it is confined to the 20 um layer that will eventually be removed and replaced, so it governs the handling procedure rather than the shielding design. It also provides an independent gamma-spectroscopy check on the integrated proton dose.



WP3

Selecting the paraffin thickness

The flux entering the moderator is **2.714×10^{-5} neutrons per primary**. The thickness was scanned at 10^8 primaries per point, recording both the total flux leaving the paraffin and the thermal component (below 0.025 eV).

Thickness	Total out	Thermal out	Thermal frac.
1 cm	2.242e-05	1.14e-08	0.05%
4.5 cm	1.278e-05	7.01e-07	5.49%
5 cm	1.157e-05	8.385e-07	7.25%
5.5 cm	1.021e-05	8.381e-07	8.21%
7 cm	6.828e-06	6.12e-07	8.96%
50 cm	0	0	-

The thermal fraction rises monotonically with thickness, whereas the thermal flux peaks at 5 cm and then falls as absorption takes over. Production scales with flux, so **5 cm** was selected.

WP4

Selecting the 6Li thickness

A ^{6}Li shell encloses the paraffin so that thermalised neutrons meet it radially. Capture was scored with USRBDX and the product nuclei with RESNUCLEI, at 10^8 primaries per point.

6Li thickness	Capture eff.	3H / primary	Mass
0.01 cm	27.7%	1.910e-06	0.91 g
0.1 cm	61.4%	5.78e-06	9.3 g
1 cm	80.5%	7.93e-06	108 g
10 cm	94.3%	9.50e-06	3.5 kg
50 cm	99.7%	1.008e-05	166 kg

Increasing the thickness from 0.01 to 50 cm raises the capture efficiency from 28% to 99.7%, a factor of 3.6, at a cost of 360 litres and 166 kg of enriched ^{6}Li, which is expensive and strategically controlled, and a shell of that mass is a structural problem in itself.

2.384×10^5 s^{-1}

3H NUCLEI AT 1 UA AND 2% DUTY, WITH 100 UM SELECTED

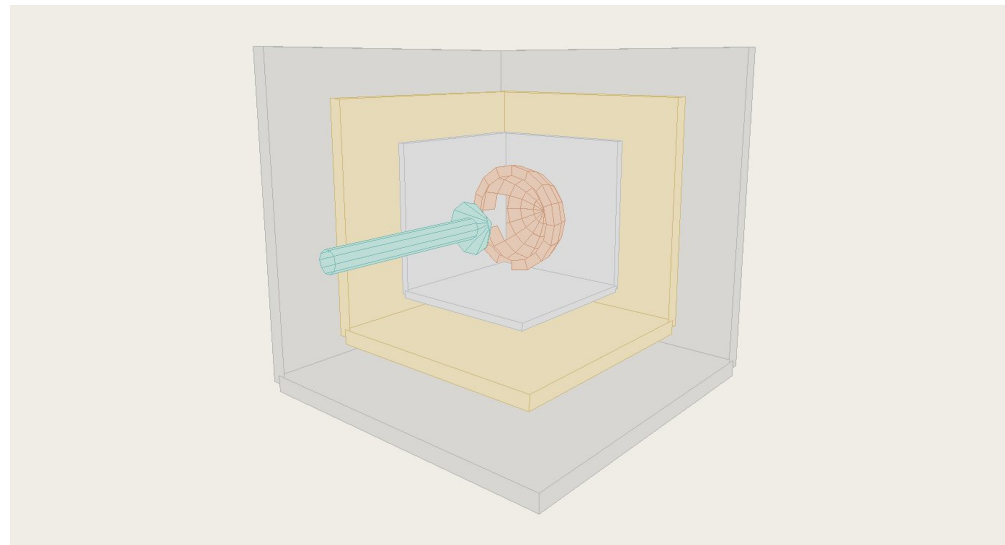
WP4

Dose equivalent and the three-layer shield

Dose equivalent is the absorbed energy per unit mass weighted by the biological damage each radiation type causes, in sieverts; neutrons carry the higher weighting factor. It was scored with the FLUKA **DOSE-EQ** card at 10^8 primaries, neutrons and photons separately, with raw output in pSv per primary converted to Sv/h. The 2.5 uSv/h limit for occupied areas follows ICRP as adopted in NDK regulation.

Case	Dose equivalent	vs limit
unshielded, 1 uA	4.54e-09 Sv/h	550x below
unshielded, 1 mA	4.54e-06 Sv/h	1.8x over
shielded, outside	2.5e-10 Sv/h	10 000x below

At 1 mA the dose falls to 2.35×10^{-7} at 60 cm, so shielding becomes mandatory. The shield has three layers: **1 mm Al** stops low-energy secondary charged particles and beta radiation at source; **15 cm borated paraffin** — the hydrogen moderates the fast neutrons and the boron then absorbs them; and **40 cm concrete** for the primary gammas and the capture gammas produced by the boron.



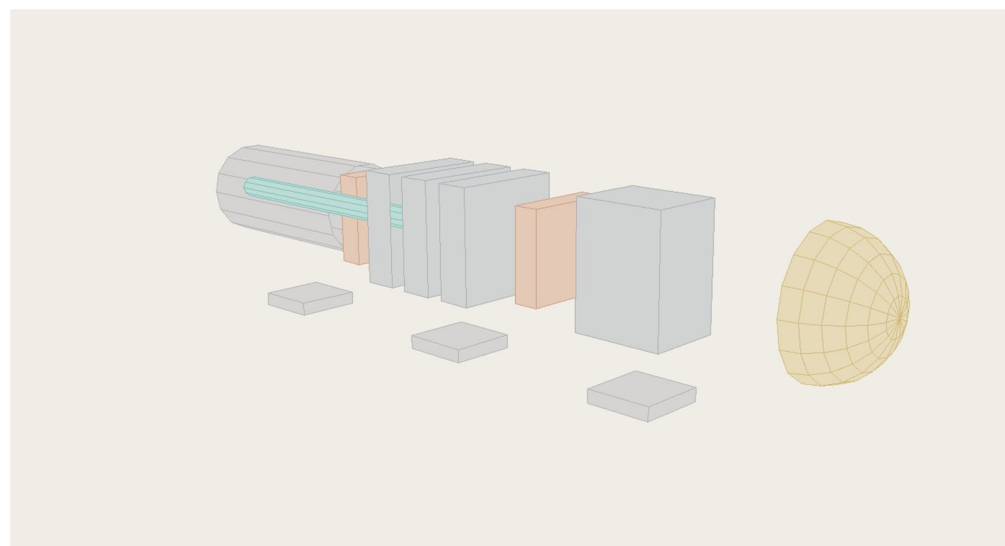
WP2 / WP5

Thermal analysis, beamline and magnets

Why ANSYS? FLUKA was used to observe the deposited power, but it cannot model conduction, fluid flow or chiller systems. Pure lithium melts at about 180 C in under two seconds, which made the switch necessary. Resolving the full 300 s was computationally impractical, so an equivalent **1 Hz cycle** was used at the same mean power and duty factor: if the 1 Hz model is safe, our 200 Hz machine is safe.

The beamline was fitted into a strict **4 m** distance from the RFQ exit to the laboratory garden door, modelled in SOLIDWORKS. The dipole bend angle is fixed at **10 degrees** by the room. Optics were computed with DemirciPRO, our in-house code, and cross-checked with TRAVEL: the beam reaches the target at **0.3 mm RMS with zero particle loss**.

The **quadrupole triplet**, the **steerers** and the **dipole** have all been delivered. On the bench at 13.3 A the triplet measured 1727 G against 1727.3 G predicted, and the PT100 thermal test reached about 55 C, matching the steady-state model. The steerers give 4.4 mrad deflection at 3 A with homogeneity better than 0.2% across +/-1 cm, at 12.6 W and a 1.4 K rise, so no cooling is needed.



WP5

The injector and the diagnostics

RFQ work started at TAEK, now TENMAK NUKEN, at 352 MHz. KAHVELab designed and built an **800 MHz cavity in two modules**, the world's highest-frequency proton RFQ. The higher frequency enables a smaller cavity, delivering 2 MeV under 1 m for full transportability. Operating parameters: 1 mA peak current, about 1% duty factor and about 30% injected-proton capture. The same cavity also supports portable PIXE for materials analysis, archaeology and museum applications.

For the scintillator screen, three criteria were applied before any simulation: high light yield, slow degradation of the light output under irradiation, and no afterglow. CsI(Tl), NaI(Tl) and P46 were scanned in Geant4 from 10 to 50 um. CsI(Tl) and NaI(Tl) retain their yield per MeV as the film is thinned, whereas P46 loses roughly half of it. Based on the analysis outputs we selected **P46 (10 um), P43 (50 um) and NaI(Tl) (10 um)**, with an aluminium backing to distribute the generated heat.

The Faraday cup was modelled in CST as three layers: a copper collector 5.0 cm deep and 5.5 cm wide, a 0.3 cm PTFE insulator and a 0.5 cm copper guard ring held at **-200 V**. Leakage is zero under all three emission models tested. The design and analysis processes for the Faraday cup are not yet complete, but work is continuing.

SUMMARY

Planned for the next period

- Delivery and testing of the RFQ; initiation of the measurement box and remote detector control.
- WP6: construction of the shielding structure and acquisition of the NDK licence or exemption.
- WP8: target manufacture and commissioning of the gas collection system.
- Scintillator analysis is complete; currently working on the arrival of the scintillator screens.

Further information and questions

phy.net.tr/kahvelab

Project details, publications and contact information for the group.

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