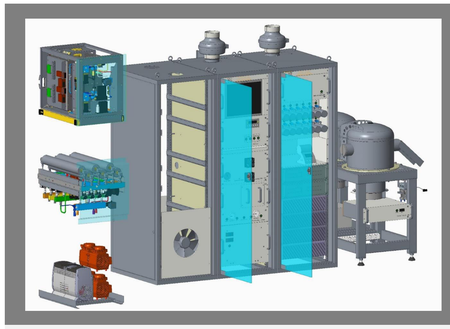
SAUNA-III new beta detector performance

To achieve the design requirements for the SAUNA-III radio-xenon measurement system a new beta detector cell has been developed. The new detector was designed to handle the considerably larger sample size and the change in carrier gas from helium to nitrogen, with maintained or improved detector sensitivity and energy resolution. The first detectors of the new design have been produced and installed in the SAUNA-III prototype and measurement results can be compared with the Monte-Carlo simulations that were used in the design of the new detector. The detector performance has been studied with respect to gas composition, sample size and cell pressure.



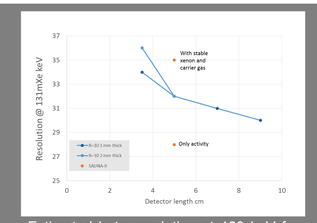
Required MDC
(Minimum Detectable Concentration)

Isotope	mBq/m³
^{133}Xe	< 0.3
^{131m}Xe	< 0.3
^{133m}Xe	< 0.3
^{135}Xe	< 1

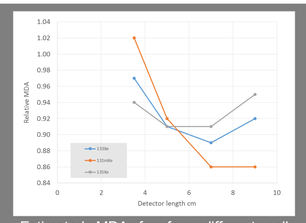
Specification	Req.	SAUNA III	SAUNA II
Cross-contamination	0.1%	0.12%	0.3 %
Processing time		5.3 h	7 h
Xenon volume, in detector	Set by MDC	3.0 ml	1.2 ml
Collection time	6 h	6 h	12 h
Memory effect	0.2%	0.06%	

SAUNA-III system design and requirements

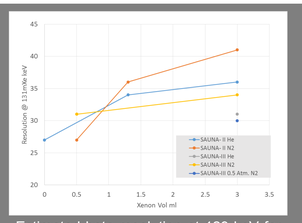
SAUNA-III is designed as an upgrade to an existing SAUNA-II system that shortens the collection time to 6 hours with preserved (or improved) sensitivity. The main change is the replacement of all parts in the first sampling rack, compressors, Pressure Swing Adsorption xenon concentration and a faster dual-sampling oven.



Estimated beta resolution at 129 keV for different cell lengths and scintillator thickness for 20 mm diameter cells compared to a standard SAUNA II cell.



Estimated MDA for four different cell lengths relative to a SAUNA-II cell (20 mm diameter vs 15 mm for the SAUNA-II cell). The MDA depends on: electron energy resolution, photon efficiency and cell length.



Estimated beta resolution at 129 keV for different sample sizes. SAUNA-II and SAUNA-III cells using N_2 and He as carrier gas

Detector simulations

Using Geant-4 different detector dimensions were explored in order to find the best design to optimize sensitivity and resolution for an increased xenon sample volume, while requiring the cell to be small enough to fit inside the existing SAUNA-II NaI detector.

β–γ coincidence detector

Design limitations:

Should fit inside lead shield and NaI-Crystal: ∅10.2 cm x 10.2 cm, 3.6 cm through-side well (β-PMT, gas line and QC source has to fit inside)

New β-detector: ∅2.0 cm x 7.3 cm, 1.2 mm thick. Inner volume=17.2 cm³, 3 x effective volume, 2 x more plastic

New PM-tubes, active diam. 25 mm, 28% quantum efficiency

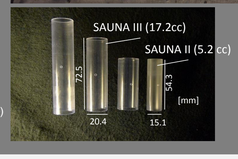
Fits inside SAUNA II lead shield

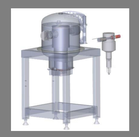
New cells produced locally.

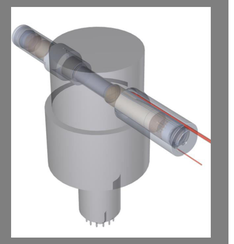
Large cells cut using diamond tool (both inside and outside)

Teflon reflector replaced with White98™ Film

ALD coating to minimize memory effect (now limited by other parts)

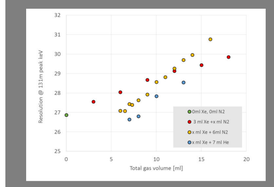


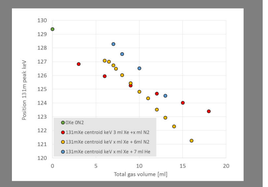




Production of new cells and detector design

To verify the simulations and to test if the production of new cells could be improved, several cells were manufactured from bulk scintillator plastic. SAUNA-II type cells and cells with the larger diameter, in three different lengths, were manufactured and tested. Thanks to the larger inner diameter, cells can be cut in a lathe using a diamond tool. The resulting smooth surface results in a good energy resolution and less degradation in the ALD process. A new simplified detector holder has also been designed which is assembled from only a few pieces of plastic.





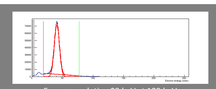
Measurements on test cell

Measured beta resolution at 129 keV and peak position using ^{131m}Xe spikes in SAUNA-III cells. The green point is with the cell evacuated and only active xenon injected. Yellow and blue points have a fixed carrier gas volume of either nitrogen or helium and varying sample size (stable xenon). The red points have 3 ml of stable xenon (SAUNA-III sample) and varying nitrogen carrier gas volumes.

Improved efficiencies

ROI	SAUNA III	SAUNA II SEX63_004
2	0.56	0.48
3	0.60	0.61
4	0.62	0.58
5	0.61	0.55
6	0.61	0.55

Add reduced dead volume factor >10% improved sensitivity



MDC for 5 h gas background + 5 h sample

Isotope	Requirement mBq/m³	Achieved mBq/m³
^{133}Xe	< 0.3	0.15
^{131m}Xe	< 0.3	0.1
^{133m}Xe	< 0.3	0.1
^{135}Xe	< 1	0.3

Results in SAUNA-III

The SAUNA-III detector more than fulfils sensitivity requirements, while supporting the improved reporting time offered by SAUNA-III. The first PREL-file is available 13.5 h after collection start and the sample is archived after 20.5 h (as a comparison, the SAUNA-II first PREL-file is produced after 20.5 h)

Conclusion

A new beta cell has been developed for SAUNA-III that is compatible with the current NaI detector, lead shield and detector electronics. The new detector with 3 ml xenon and nitrogen as carrier gas has, thanks to improved design and manufacturing process, better performance than a typical SAUNA-II detector. In addition to several test cells, four complete detectors have been produced with consistent performance.

Authors

Anders Axelsson, Tomas Fritioff, Anders Mörtsell and Anders Ringbom
FOI, Swedish Defence Research Agency

www.foi.se