Detection of Breeding Blankets Using Antineutrinos

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Talk for AAP 2015 Annual Meeting

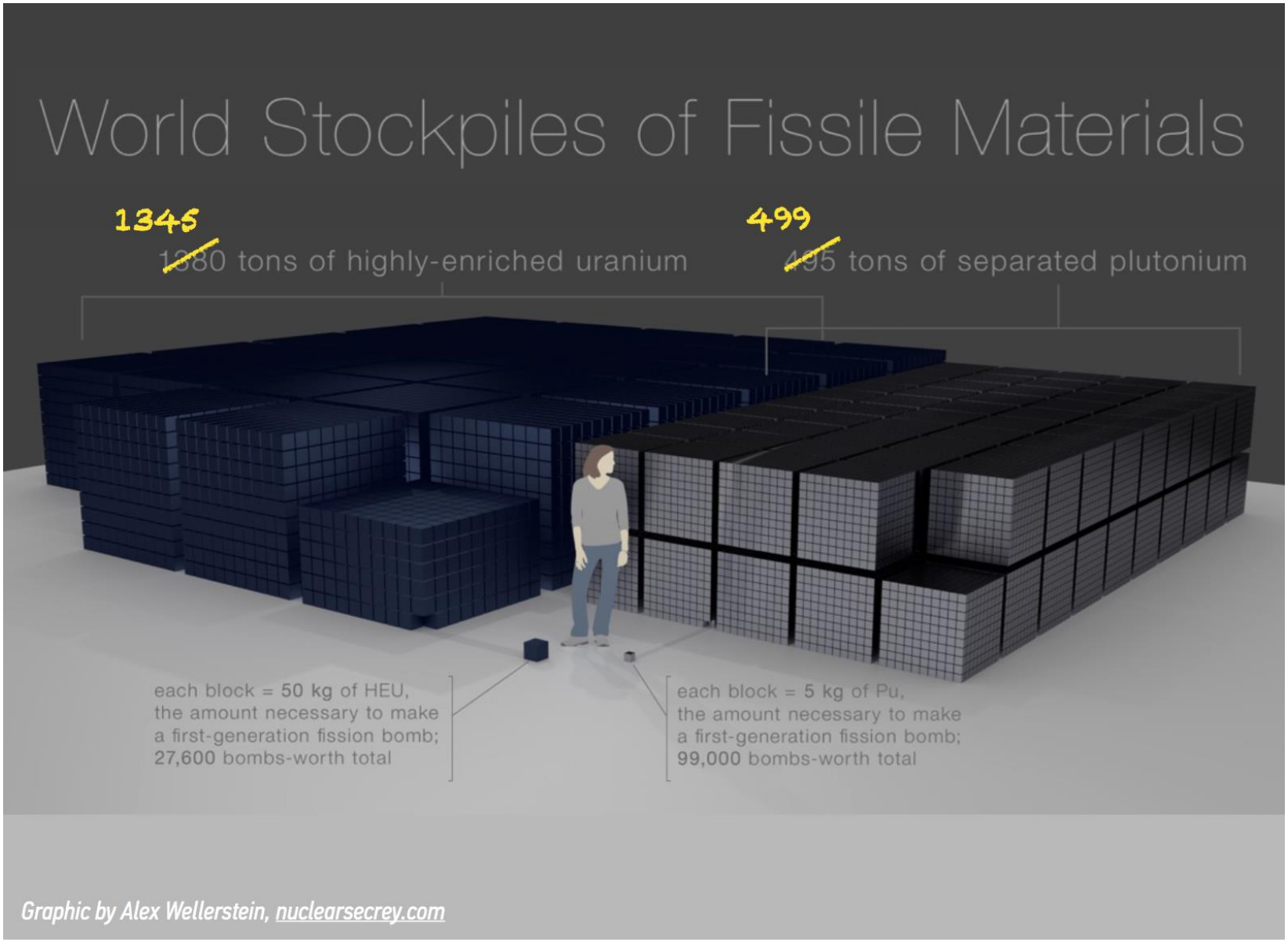
Arlington, Virginia

Image: Liam Brummitt website

30-Second Preview

1. Need for monitoring plutonium disposition
2. Connection between fast reactors, breeding blankets, and antineutrinos
3. Approach for detecting a breeding blanket using antineutrinos
4. Results demonstrating proof of principle
5. Next steps needed for proof of usefulness

Nuclear Arms Control



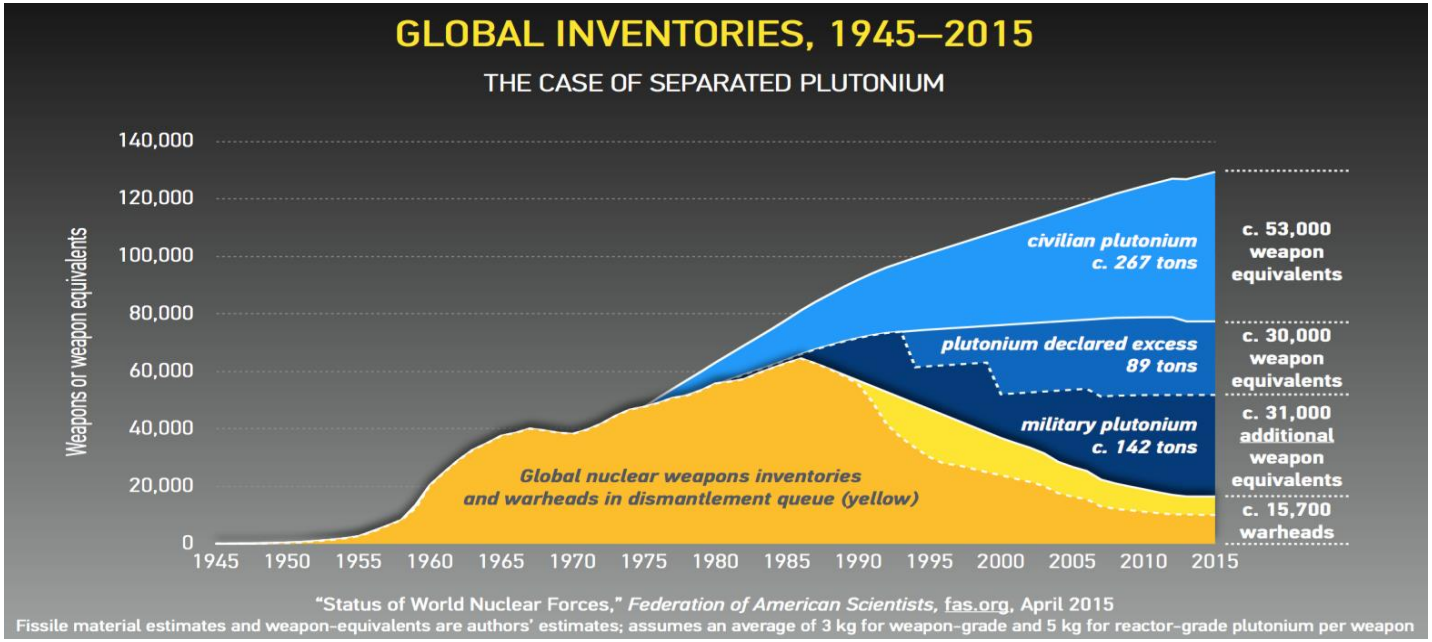
Plutonium Material Disposition Agreement

U.S.-Russia agreement

Each dispose of 34 MT of Pu-239 declared excess to military use

U.S. disposition - MOX burning in LWRs

Image: NTI 2010



PMDA Article III.3

2010 Amended Protocol:

Russia decides to burn excess plutonium in fast reactors

"The radial blanket of the BN-600 reactor will be completely removed before disposition of conversion product begins in it, and the BN-800 will be operated with a breeding ratio of less than one for the entire term of this Agreement."

PMDA Article III.3

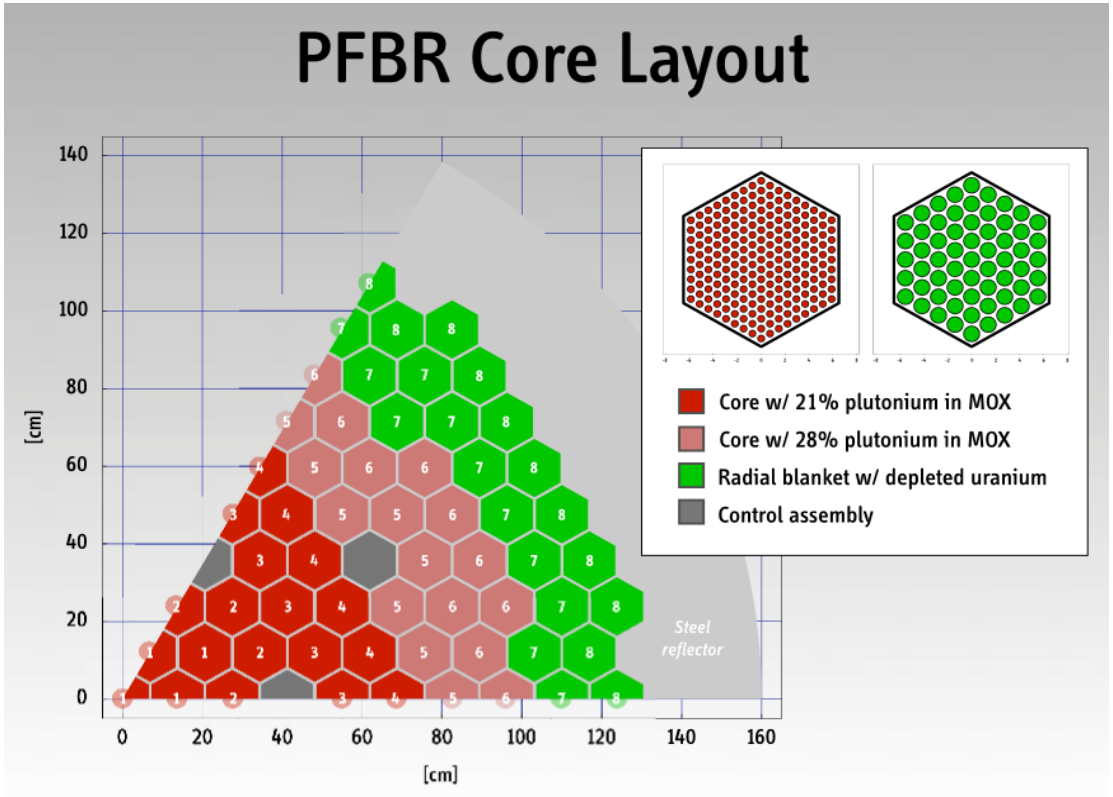
Trust, but verify.

"The **radial blanket of the BN-600 reactor will be completely removed before disposition of conversion product begins in it**, and the BN-800 will be operated with a breeding ratio of less than one for the entire term of this Agreement."

Fast Breeder Reactors

Goal for the PMDA is to monitor the blanket signal

Image: Glaser *et. al*, Science & Global Security 15 (2007)



Fast neutrons drive core fission and neutron capture in a surrounding blanket of NU or DU where Pu-239 breeding occurs

Reactor Electron Antineutrinos

Goal for the PMDA is to monitor the blanket signal

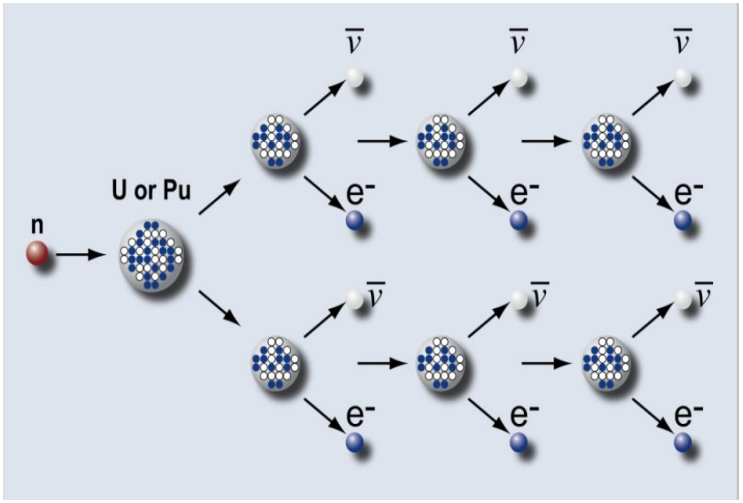
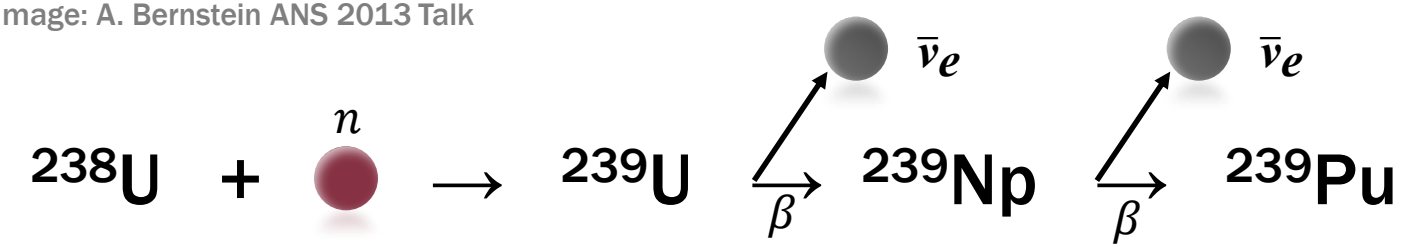


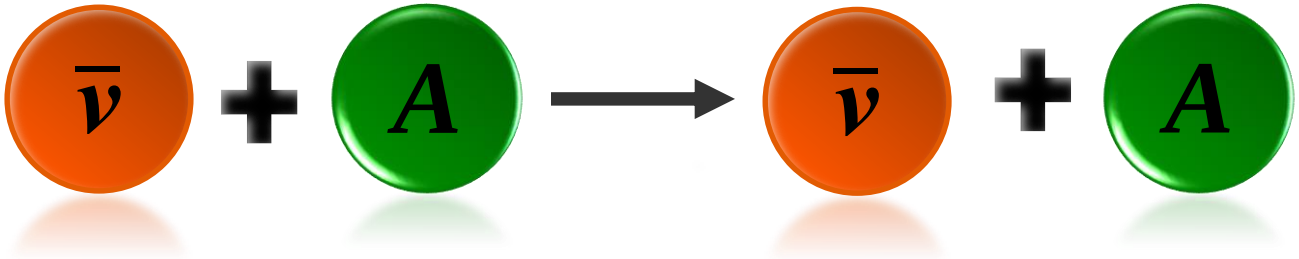
Image: A. Bernstein ANS 2013 Talk

6 emitted per fission from beta decay of U and Pu fission fragments, energy range up to 12 MeV



2 emitted per capture from fast neutrons on U, energy up to 1.26 MeV

Coherent Antineutrino Detection



Coherent elastic neutrino-nucleus scattering (CENNS)

Threshold-less reaction

Cross section σ_{vA}~ 10^{-39} cm^2

Small nuclear recoils - few eV to keV

$$\frac{d\sigma}{dT}(E_\nu) = \frac{G_F^2}{4\pi} N^2 M_N \left(1 - \frac{M_N T}{2E_\nu^2}\right) \quad , \quad T_{max} = \frac{E_\nu}{1 + \frac{M_N}{2E_\nu}}$$

Prototype Fast Breeder Reactor

Image: Mitra Talk (BHAVINI)

Fast reactor being built in India

Full 3-D simulation

Look at fresh blanket signal during first 90 days

Model and data taken from:
A. Glaser and M. V. Ramana, Science & Global Security 15 (2007)

Safeguards on Future Indian Fast Reactors

3 Phase Agenda…

Phase 2: Pu-239 breeders

Phase 3: U-233 breeders

Safeguards…

PFBR – No.

Future commercial fast reactors – Yes.

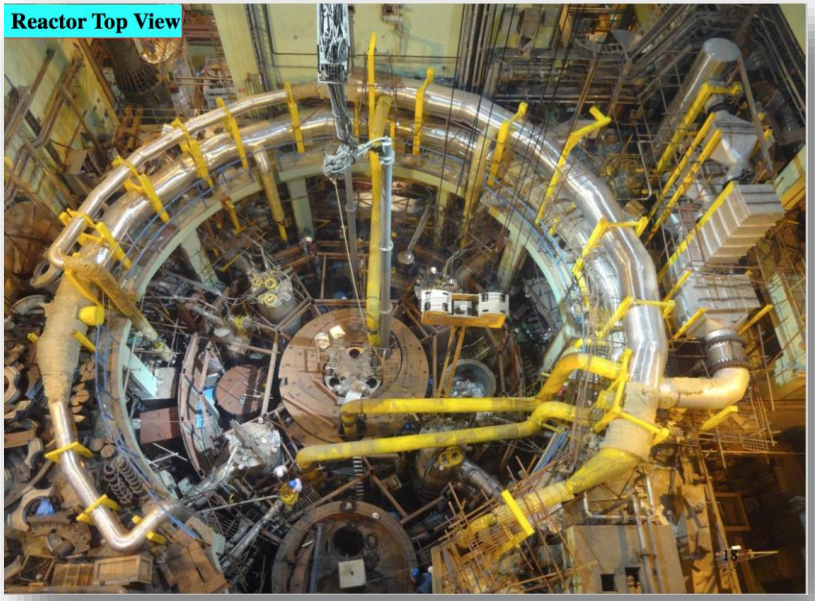


Image: Mitra Talk (BHAVINI)

Fissile Material Cutoff Treaty (FMCT)…

Ban production of FM for weapons

Strictly monitor civilian FM production

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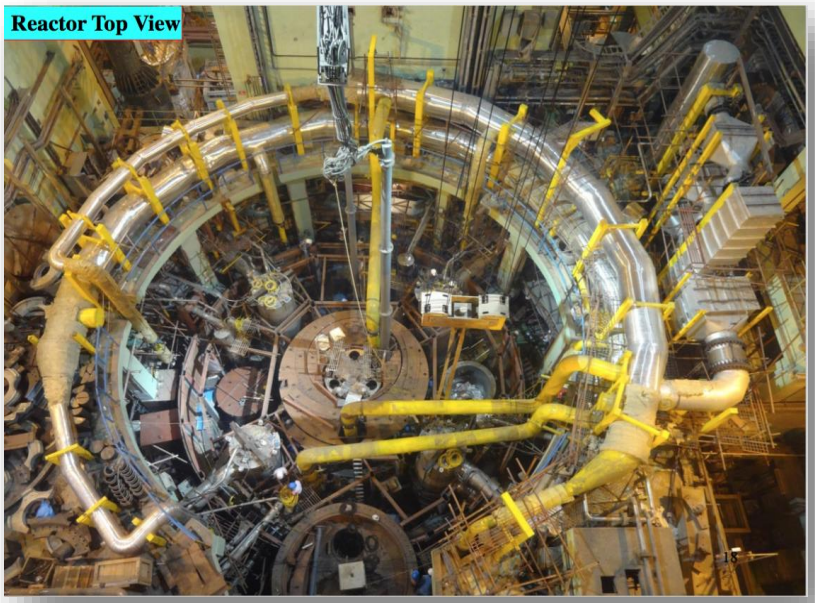


Image: Mitra Talk (BHAVINI)

Fissile Material Cutoff Treaty (FMCT)…

Ban production of FM for weapons

Strictly **monitor civilian FM production**

Analysis: Set-up and Statistics

- Assume perfect detection efficiency
- Use surface deployment 25 m from core
- Examine various target materials to gauge rate vs. threshold tension
- Use standard chi-squared analysis
- Assume flat background distribution
- Leave reactor power free in fit

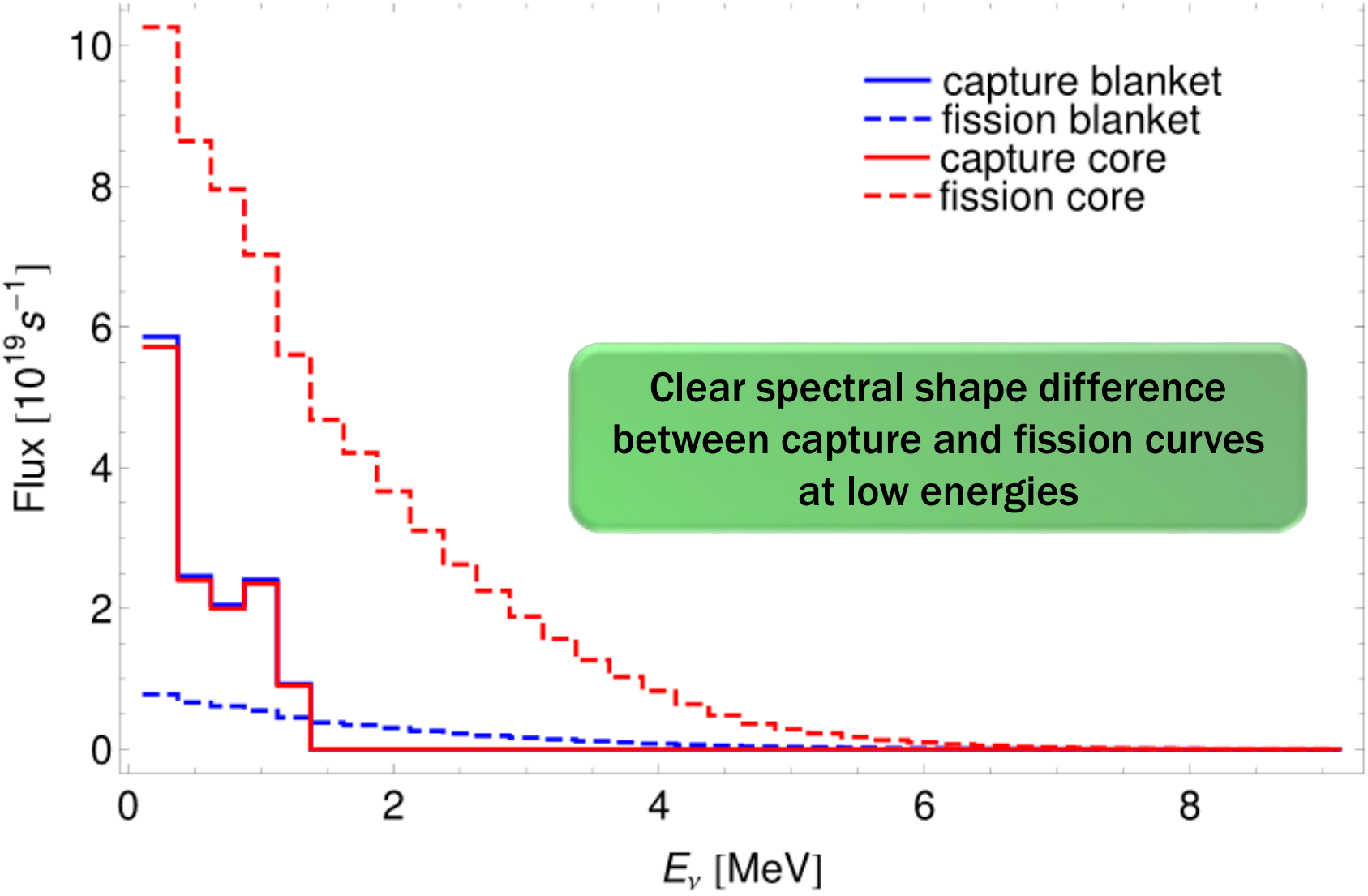
NEW Preliminary Results

Raw detected event rates

Material	Core Fission	Core Capture	Blanket Fission	Blanket Capture	Max Recoil [eV]
^{2}H	7,943	183	733	**188**	1,675
^{4}He	15,886	367	1,466	**376**	838
^{28}Si	111,205	2,569	10,259	**2,634**	120

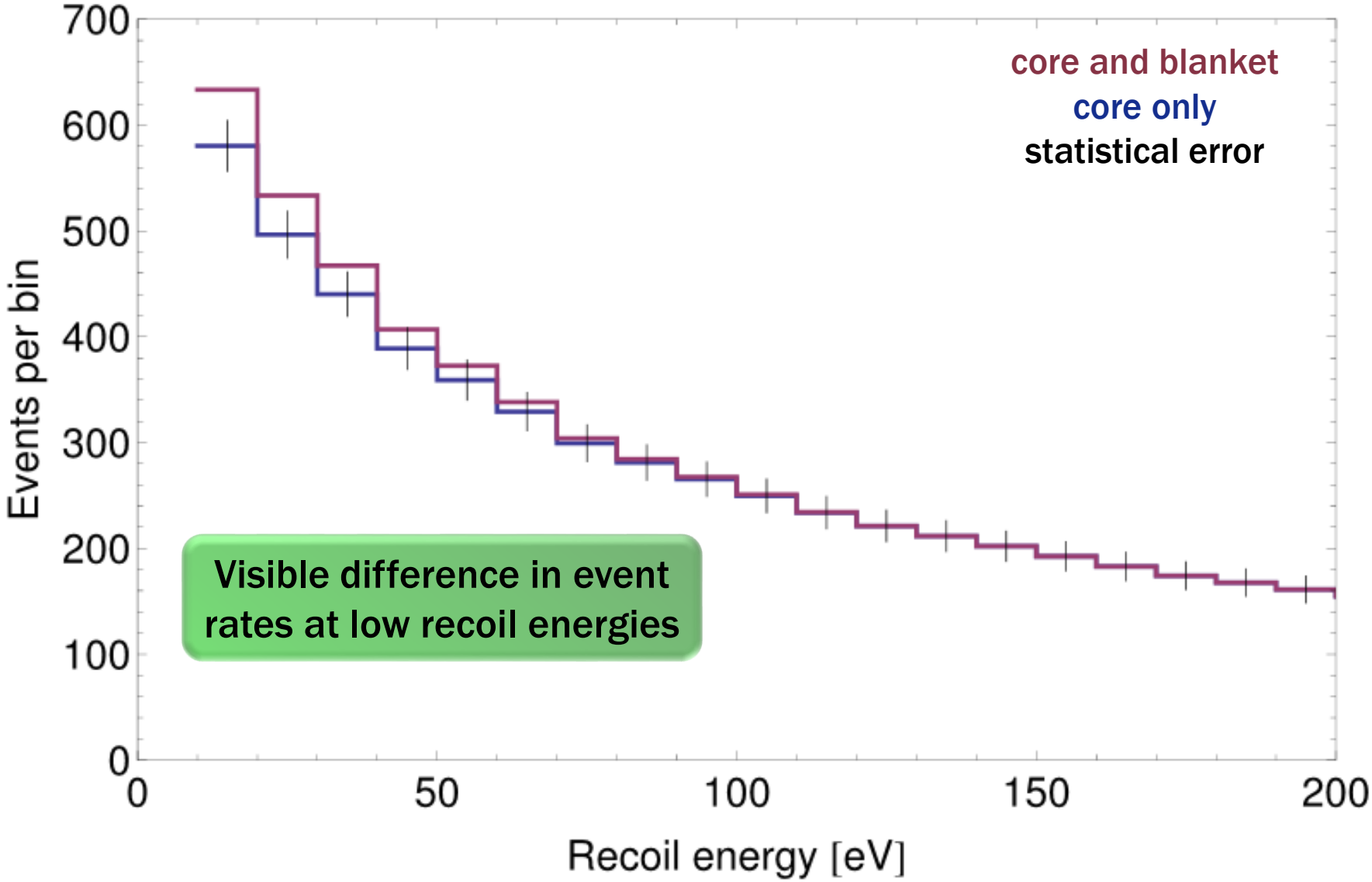
100 kg detector at 25 m stand off for 90 days

Contribution to Total Antineutrino Flux

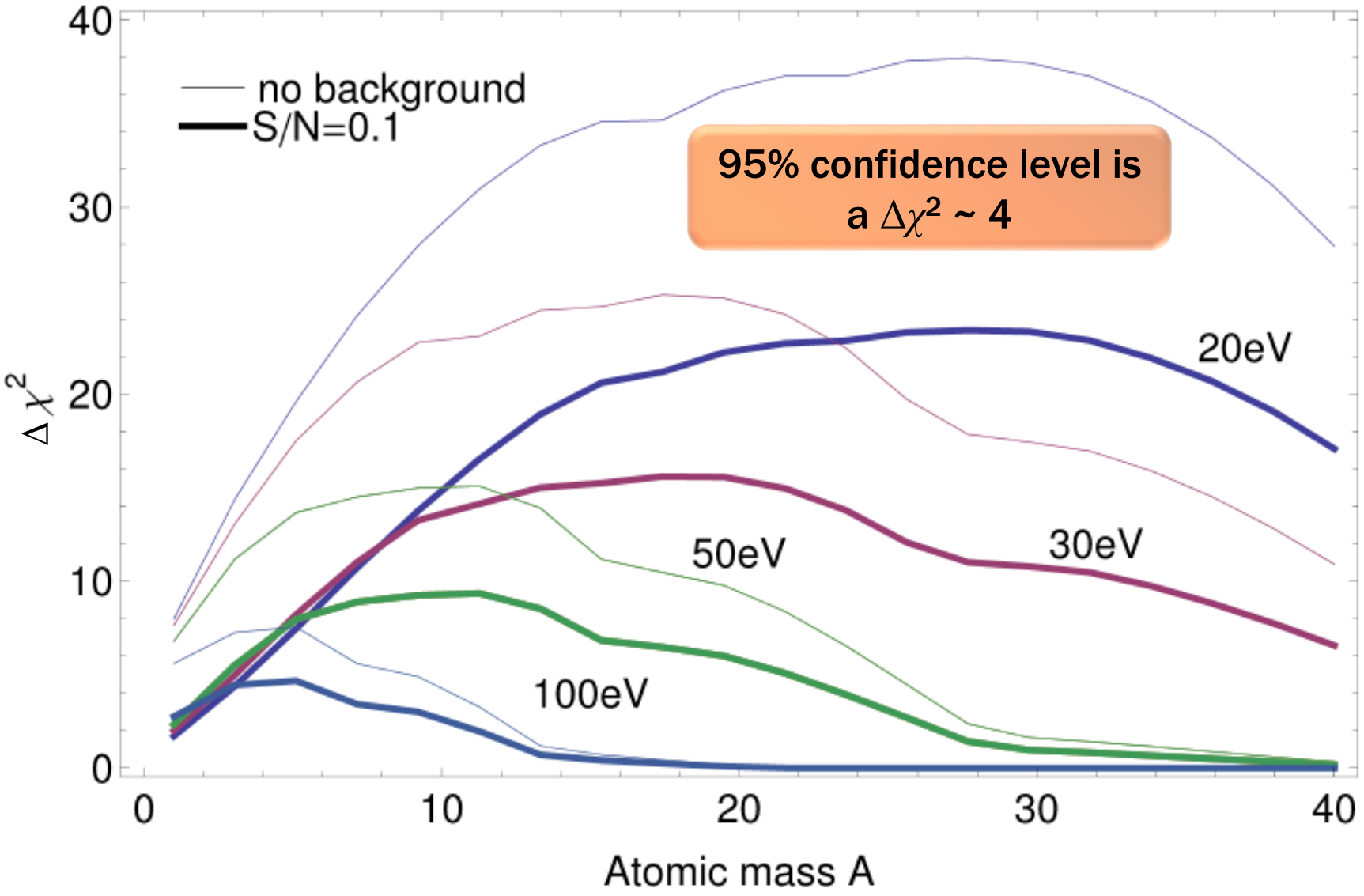


Clear spectral shape difference between capture and fission curves at low energies

NEW Raw Event Rates for 10 kg of ^{28}Si



NEW $\Delta\chi^2$ Sensitivity Analysis



Achieved: Proof of Principle

- On-going R&D on silicon-based charge coupled devices (CCDs) shows detector masses of 17-kg with 20 eV threshold may be possible in the near future[1]
- Can detect the presence of a breeding blanket at a PFBR-type fast reactor at 95% confidence level within 90 days using a 36-kg ^{28}Si CENNS detector with a threshold of 30 eV[2]

[1]G. Fernandez Moroni, J. Estrada, E. E. Paolini, et al., Phys. Rev. D 91, 072001 (2015); [2] Cogswell and Huber INMM Proceedings 2015

NEXT STEPS: Proof of Usefulness

Can CENNS or a combination of CENNS+IBD data help estimate…

Pu-239 mass in the blanket

Grade of Pu-239 being burned in the core

Grade of Pu-239 bred in the blanket

SIMULATION

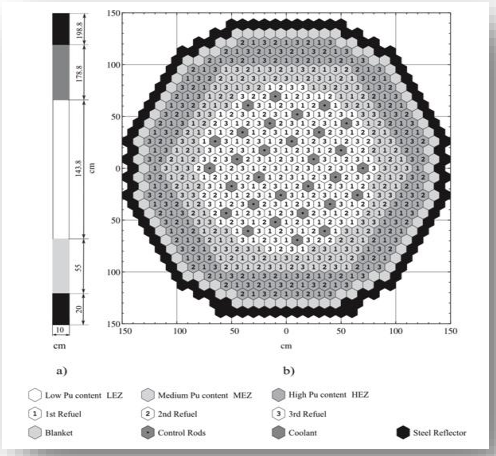
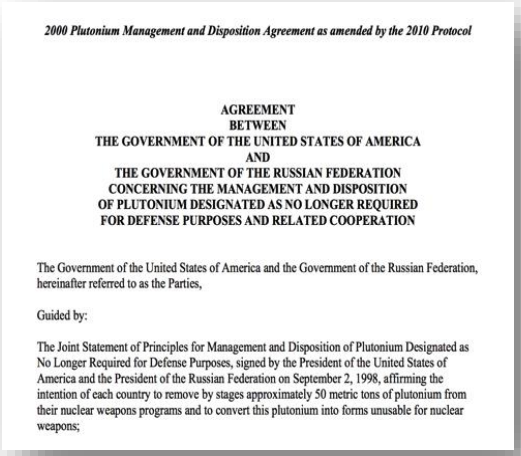


Image: Kutt et. al, SGS 22 (2014)

DEMONSTRATION

Image: World Nuclear News 2015

APPLICATION



2000 Plutonium Management and Disposition Agreement as amended by the 2010 Protocol

AGREEMENT
BETWEEN
THE GOVERNMENT OF THE UNITED STATES OF AMERICA
AND
THE GOVERNMENT OF THE RUSSIAN FEDERATION
CONCERNING THE MANAGEMENT AND DISPOSITION
OF PLUTONIUM DESIGNATED AS NO LONGER REQUIRED
FOR DEFENSE PURPOSES AND RELATED COOPERATION

The Government of the United States of America and the Government of the Russian Federation, hereinafter referred to as the Parties,

Guided by:

The Joint Statement of Principles for Management and Disposition of Plutonium Designated as No Longer Required for Defense Purposes, signed by the President of the United States of America and the President of the Russian Federation on September 2, 1998, affirming the intention of each country to remove by stages approximately 50 metric tons of plutonium from their nuclear weapons programs and to convert this plutonium into forms unusable for nuclear weapons;

Image: 2010 PMDA Protocol

Thank You!

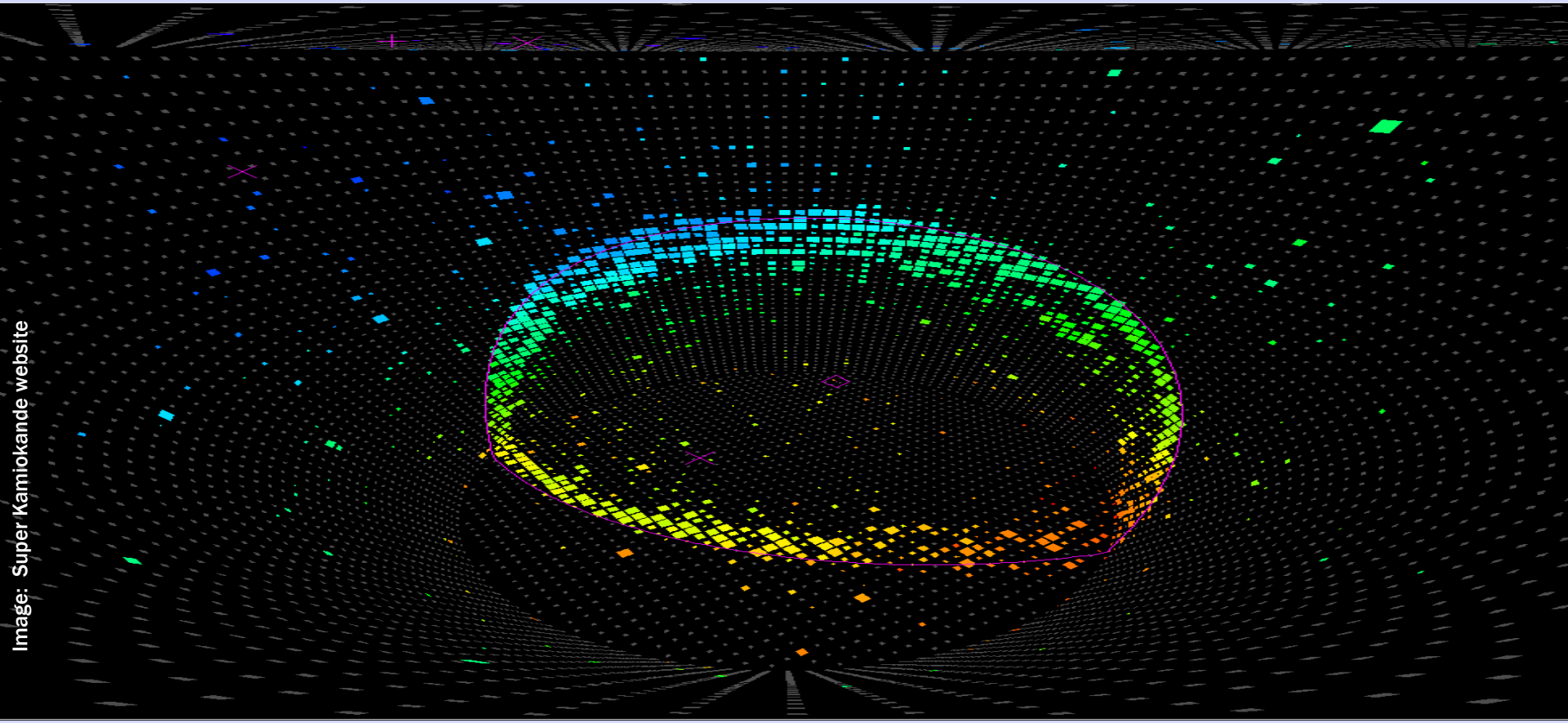


Image: Super Kamiokande website

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