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September 24, 2015

U.S. Nuclear Regulatory Commission
Region III Office
2443 Warrenville Road, Suite 210
Lisle, IL 60532-4352

Attn: Mr. Kevin Null
Subj: Requested Amendment of NRC License Number 21-35144-02

Mr. Null:

The enclosed letter is to address the three issues you identified in the conversation record from 09/17/2015 and to notify you about the temporary leave of Niowave's RSO, Eric Maddock. Please let us know if you have further questions.

Sincerely,

Dr. Terry L. Grimm, Ph.D.
President and Senior Scientist

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Region III Office
2443 Warrenville Road, Suite 210
Lisle, IL 60532-4352

To: Mr. Kevin Null
From: Dr. Valeriia Starovoitova

Subj: Requested Amendment of NRC License Number 21-35144-02

Mr. Null,

Below we address the concerns you outlined in the conversation record from 09/17/2015 and inform you about the temporary absence of Niowave's RSO, Eric Maddock.

1. For the higher end request, you will need to provide a specific ceiling, e.g., 19.75%. We will not accept <20%. There is too much uncertainty that you will able to stay under 20% with the known tolerance variations.

We agree to provide a specific ceiling of 19.99%. As you can see in the attached LEU specification data sheet provided to us by Y-12, the enrichment of uranium targets we are interested in acquiring is listed as 19.75 ± 0.2 %. This is a typical variation in weight % of U-235 and thus possible assay range is 19.55% - 19.95%. To be able to acquire this material we request the following change to the conditions of our license:

Replace the paragraph on page 1 of the NRC Form 313 "Accelerator Produced Radionuclides" Continuation of Responses dated 2/11/2015 that reads:

> The special nuclear material (SNM) proposed for this license is low enriched uranium (LEU) in solid form where the U-235 *enrichment is greater than the naturally occurring abundance but less than 20%* by weight. We will not exceed the maximum possession limits for the contained U-234, U-235, or U-238 as outlined in Table 5.1. See Figure 5.1 for how the proposed possession limit for LEU varies based on enrichment of U-235. See Table 6.1 for a description of the chemical and physical form of these isotopes and a description of their use.

With (changes in *italics*):

> The special nuclear material (SNM) proposed for this license is low enriched uranium (LEU) in solid form where the U-235 *enrichment is greater than the naturally occurring abundance but less than 19.99%* by weight. We will not exceed the maximum possession limits for the contained U-234, U-

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235, or U-238 as outlined in Table 5.1. See Figure 5.1 for how the proposed possession limit for LEU varies based on enrichment of U-235. See Table 6.1 for a description of the chemical and physical form of these isotopes and a description of their use.

If you have further questions, our points of contact at Y-12 are Becky Eddy (865-576-4119, Becky.Eddy@npo.doe.gov) and Elaine Parker (865-576-2871, Elaine.Parker@cns.doe.gov).

2. Submit procedures that will be implemented to verify that what you receive does not exceed possession limits, or the percent enrichment that you commit to stay within.

To verify the mass of the received material we will be using a calibrated scale. Verification of the enrichment is more complicated and it is described below in details.

Gamma ray analysis for uranium enrichment determination is a rather standard procedure which has been described elsewhere, for example by Clark, 1996. [1]. Niowave has all the necessary equipment for high resolution gamma spectrometry, so the LEU enrichment will be determined by finding the ratio of activities of U-238 and U-235.

Pure U-235 has a strong gamma peak at 185.71 keV, which can be used for spectroscopy. Additionally, U-235 relatively quickly decays to equilibrium with its daughters, Th-231 and Pa-231, which can also provide reliable information on U-235 activity. Pure U-238 emits rather weak gamma lines, but its daughters (Th-234, Pa-234, and U-234) are strong gamma emitters and being in equilibrium with U-238 can be used to find U-238 activity.

The isotopic abundance (for a certain isotope) is related to the observed peak intensities as:

$$I_1 = \lambda_1 A_1 B_1 \Omega_1 \varepsilon_1 \tau_1 \qquad (1)$$

where:

I_1 – peak intensity (counts/second)
$\lambda_1 = \ln 2/T_{1/2}$ – decay constant (seconds^{-1})
A_1 – number of atoms
B_1 – branching ratio
Ω_1 – solid angle of the detector
ε_1 – detector efficiency for the given gamma energy
τ_1 – gamma transmission to the detector

The ratio for two isotopes is given as:

$$\frac{A_1}{A_2} = \frac{I_1 \lambda_2 B_2 \Omega_2 \varepsilon_2 \tau_2}{I_2 \lambda_1 B_1 \Omega_1 \varepsilon_1 \tau_1} \qquad (2)$$

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where labels 1 and 2 represent measurements from two isotopes. Since only one sample is used for the measurement, the solid angle terms cancel out:

$$\frac{A_1}{A_2} = \frac{I_1 \lambda_2 B_2 \varepsilon_2 \tau_2}{I_2 \lambda_1 B_1 \varepsilon_1 \tau_1} \tag{3}$$

As an example of such calculations we performed uranium enrichment determination for some natural uranium samples that we have in stock. Two peaks were used for the calculations: 185.71 keV for U-235 and 1001 keV for U-238. The enrichment was calculated as:

$$wt\_\% = \frac{M_{U-235}}{M_{U-235} + M_{U-238}} \times 100\% \tag{4}$$

Since both U-235 and U-238 are naturally radioactive, their mass can be found using decay rates and their half-lives. Note that the numbers of radioactive nuclides are:

$$N(t) = N_0 e^{-\lambda t} \tag{5}$$

Therefore decay rate (activity) is:

$$A(t) = \frac{dN}{dt} = N_0 \lambda e^{-\lambda t} \tag{6}$$

Due to long half-lives of U-235 and U-238 (7.04E8 year and 4.47E9 year respectively), $\lambda \rightarrow 0$ and $e^{-\lambda t} \rightarrow 1$ so the above equation can be simplified as:

$$A = N_0 \lambda \tag{7}$$

Therefore the mass of U-235 can be expressed as:

$$M_{U-235} = \frac{235 N_0}{N_A} = \frac{235 A_{U-235}}{N_A \lambda_{U-235}} \tag{8}$$

And the mass of U-238 can be expressed as:

$$M_{U-238} = \frac{238 N_0}{N_A} = \frac{238 A_{U-238}}{N_A \lambda_{U-238}} \tag{9}$$

Therefore the enrichment can be found as:

$$wt\_\% = \frac{1}{1 + \frac{A_{U-238}}{A_{U-235}} \frac{\lambda_{U-235}}{\lambda_{U-238}} \frac{238}{235}} \times 100\% \tag{10}$$

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The ratio of activities of U-235 and U-235 was found using Eq. 3. from a gamma spectrum obtained with the HPGe detector setup (see Figure 2).

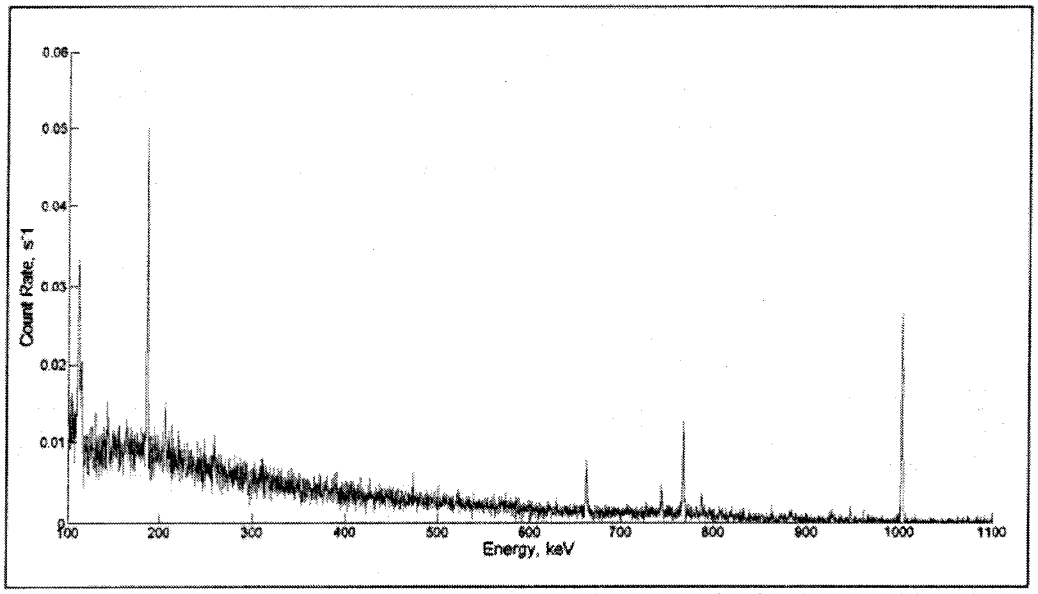

Figure 1. A gamma spectrum from a natural uranium sample (background is subtracted).

The parameters we used for the calculations are summarized in Table 2. The detector efficiency as a function of energy has been measured for several positions using a set of calibration sources (Figure 2).

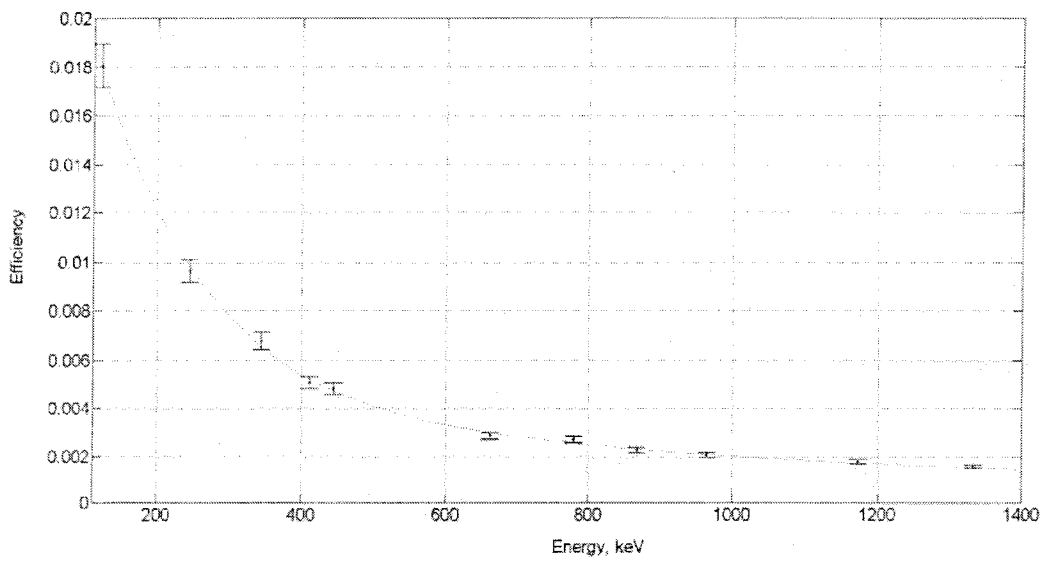

Figure 2. Efficiency curve for Niowave's HPGe detector.

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Transmission to the detector is energy depended and will be calculated for particular sample geometry. Branching ratios and half-lives will be found in references, for example [2]. Peak intensities will be found by subtracting the background and Gaussian fitting to the peaks.

Table 2. Summary of the parameters used to estimate the ratio of two isotopes.

	U-235 peak	U-238 (Pa-234m) peak
Energy of the peak, keV	185.71	1001
Intensity of the peak I, counts/s	0.4561	0.2291
Decay constant λ, 1/second	9.8458e-10	1.5507E-10
Gamma intensity B, %	57	0.84
Detector efficiency ε	0.00101	0.00016
Mass attenuation coefficient, cm^2/g	2.01	7.90E-2

Using the above method the enrichment of the sample was found to be 0.76 ± 0.17% which is consistent with the expected enrichment of 0.72% of natural uranium.

3. Describe procedures that will be implemented in the event that you receive material outside of the range that is described in your license.

In case we receive the material outside of the range that is described in our license, we will notify the NRC immediately, store the material safely and securely in the designated area, and will initiate the return process.

4. Submit clarification on the Military Leave of Niowave's RSO, Eric Maddock.

Eric Maddock was activated to Active Duty in July 2015. He is expected to be back at Niowave in late June 2016. While he is gone, Dr. Valeriia Starovoitova is serving as the Acting RSO. Amanda Grimm remains our Assistant RSO. Additionally, we are currently training Stephen Barnard, a nuclear engineer, to become a second Assistant RSO in the near future.

References:

[1] DeLynn Clark, U235: A Gamma Ray Analysis Code for Uranium Isotopic Determination, 1996, LLNL Report, UCRL-ID-125727

[2] Lammer, M. and Schwerer, O. Handbook of Nuclear Data for Safeguards, INDC (NDS) - 248, IAEA, 1991

DRAFT Low-Enriched Uranium (LEU) Specifications for Targets

This document has been reviewed by a Y-12 DC/UCNI-RO and has been determined to be UNCLASSIFIED and contains no UCNI. This review does not constitute clearance for Public Release.
Name: Thomas Hanlon /s/ Date: 7/14/2014

Specified Item	Symbol	Units	Proposed LEU Target Specifications LEU Metal / U_3O_8 Specification Limits	EBC Factors
Uranium Purity	U	gU/g	≥0.9988 / ≥0.841	
U-232	U-232	µg/gU	≤0.002	
U-234	U-234	µg/gU	≤2600	
U-235	U-235	wt. %	19.75% (+/- 0.2%)	
U-236	U-236	µg/gU	≤4,600	
Tc-99 + Sr-90	Tc-99	Bq/gU		
TRU (Alpha)	TRU	Bq/gU	≤100.0[a]	
Beta	Beta	Bq/gU	≤5000[a]	
Activation Products	ActProd	Bq/gU	≤100.0[a]	
Fission Products	FissProd	Bq/gU	≤600.0[a]	
Moisture	H2O	ppm or µg/g oxide sample	NM[b]/≤1,032	
Density	Density	g/cm^3	NM[b]/7.8-8.5	
Surface Area		m^2/g	NM[b]/≤1.031	
Aluminum	Al	µg/gU	≤150.0	0.0000
Antimony	Sb	µg/gU		
Arsenic	As	µg/gU	TBR[c]	0.0008
Barium	Ba	µg/gU		
Beryllium	Be	µg/gU	≤1.0	0.0000
Boron	Be	µg/gU	**≤1.0**	**1.0000**
Cadmium	Cd	µg/gU	**≤1.0**	**0.3172**
Calcium	Ca	µg/gU	≤100.0	0.0002
Carbon	C	µg/gU	≤350.0/NM[b]	0.0000
Cesium	Cs	µg/gU		
Chromium	Cr	µg/gU	≤50.0	0.0008
Cobalt	Co	µg/gU	≤5.0	0.0089
Copper	Cu	µg/gU	≤50.0	0.0008
Dysprosium	Dy	µg/gU	**≤5.0**	**0.0818**
Europium	Eu	µg/gU	**≤2.0**	**0.4250**
Gadolinium	Gd	µg/gU	**≤1.0**	**4.3991**
Hafnium	Hf	µg/gU		
Iron	Fe	µg/gU	≤250.0	0.0006
Lead	Pb	µg/gU	≤5.0	0.0000
Lithium	Li	µg/gU	**≤2.0**	**0.1439**
Magnesium	Mg	µg/gU	≤50.0	0.0000
Manganese	Mn	µg/gU	≤24.0	0.0034
Mercury	Mg	µg/gU		

Molybdenum	Mo	µg/gU	≤100.0	0.0004
Nickel	Ni	µg/gU	≤100.0	0.0011
Niobium	Nb	µg/gU	TBR[c]	0.0002
Nitrogen	N	µg/gU	TBR[c]	0.0019
Phosphorus	P	µg/gU	≤50.0	0.0000
Potassium	K	µg/gU	TBR[c]	0.0008
Samarium	Sm	µg/gU	**≤2.0**	**0.5336**
Silicon	Si	µg/gU	≤100.0	0.0000
Silver	Ag	µg/gU	TBR[c]	0.0083
Sodium	Na	µg/gU	≤25.0	0.0003
Strontium	Sr	µg/gU		
Tantalum	Ta	µg/gU		
Thorium	Th	µg/gU		
Tin	Sn	µg/gU	≤100.0	0.0000
Titanium	Ti	µg/gU		
Tungsten	W	µg/gU	≤10.0	0.0014
Vanadium	V	µg/gU	≤30.0	0.0014
Zinc	Zn	µg/gU	TBR[c]	0.0002
Zirconium	Zr	µg/gU	≤250.0	0.0000
TMI (Total Impuritities)		µg/gU	≤1,000	
Equivalent Boron Content	EBC	µgEB/gU	≤3.0[d, e]	

[a] The values shown reflect the sum of the listed nuclides: Trans-U (Alpha): Am-241, Cm-243/244, Np-237, Pu-238, and Pu-239/249; Total Beta: Tc-99, Sr-90; Activation Products: Co-58, Co-60; Fission Product Activity: Sb-125, Ce-144, Cs-134, Cs-137, Nb-95, Ru-103, Ru-106, Zr-95

[b] "Not Measured" (NM)

[c] "To Be Reported" (TBR)

[d] EBC Factors are taken from ASTM C1233-09, "Standard Practice for Deterimining EBC of Nuclear Materials." EBC calculations will include: Boron, Cadmium, Dysprosium, Europium, Gadolinium, Lithium, and Samarium. Other EBC factors are provided for informational purposes only. The limit on EBC may restrict some elements to lower values than those shown in the table.

[e] The limit on EBC may restrict some elements to lower values than shown in the table.