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Containing Uranium, Plutonium, Neptunium and Americium

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LIBS Spectral Data for a Mixed Actinide Fuel Pellet Containing Uranium, Plutonium, Neptunium and Americium

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Introduction:

Laser-induced breakdown spectroscopy (LIBS) was used to analyze a mixed actinide fuel pellet containing 75% UO_2 / 20% PuO_2 / 3% AmO_2 / 2% NpO_2 . The preliminary data shown here is the first report of LIBS analysis of a mixed actinide fuel pellet, to the authors' knowledge. The LIBS spectral data was acquired in a plutonium facility at Los Alamos National Laboratory where the sample was contained within a glove box. The initial installation of the glove box was not intended for complete ultraviolet (UV), visible (VIS) and near infrared (NIR) transmission, therefore the LIBS spectrum is truncated in the UV and NIR regions due to the optical transmission of the window port and filters that were installed. The optical collection of the emission from the LIBS plasma will be optimized in the future. However, the preliminary LIBS data acquired is worth reporting due to the uniqueness of the sample and spectral data. The analysis of several actinides in the presence of each other is an important feature of this analysis since traditional methods must chemically separate uranium, plutonium, neptunium, and americium prior to analysis.

Due to the historic nature of the sample fuel pellet analyzed, the provided sample composition of 75% UO_2 / 20% PuO_2 / 3% AmO_2 / 2% NpO_2 cannot be confirm without further analytical processing. Uranium, plutonium, and americium emission lines were abundant and easily assigned while neptunium was more difficult to identify. There may be several reasons for this observation, other than knowing the exact sample composition of the fuel pellet. First, the atomic emission wavelength resources for neptunium are limited and such techniques as hollow cathode discharge lamp have different dynamics than the plasma used in LIBS which results in different emission spectra. Secondly, due to the complex sample of four actinide elements, which all have very dense electronic energy levels, there may be reactions and interactions occurring within the plasma, such as collisional energy transfer, that might be a factor in the reduction in neptunium emission lines. Neptunium has to be analyzed alone using LIBS to further understand the dynamics that may be occurring in the plasma of the mixed actinide fuel pellet sample. The LIBS data suggests that the emission spectrum for the mixed actinide fuel pellet is not simply the sum of the emission spectra of the pure samples but is dependent on the species present in the plasma and the interactions and reactions that occur within the plasma. Finally, many of the neptunium lines are in the near infrared region which is drastically reduced in intensity by the current optical setup and possibly the sensitivity of the emission detector in the spectral region. Once the optics are replaced and the optical collection system is modified and optimized, the probability of observing emission lines for neptunium might be increased significantly.

The mixed actinide fuel pellet was analyzed under the experimental conditions listed in Table 1. The LIBS spectra of the fuel pellet are shown in Figures 1- 49. The spectra are labeled with the observed wavelength and atomic species (both neutral (I) and ionic (II)). Table 2 is a complete list of the observed and literature based emission wavelengths. The literature wavelengths have references including NIST Atomic Spectra Database (NIST) [1], B.A. Palmer et al. "An Atlas of Uranium Emission Intensities in a Hollow Cathode Discharge" taken at the Kitt Peak National Observatory (KPNO) [2], R.L. Kurucz 1995 Atomic Line Data from the Smithsonian Astrophysical Observatory (SAO) [3], J. Blaise et al. "The Atomic Spectrum of Plutonium" from Argonne National Laboratory (BFG) [4], and M. Fred and F.S. Tomkins, "Preliminary Term Analysis of Am I and Am II Spectra" (FT) [5]. The dash (-) shown under *Ionic State*

indicates that the ionic state of the transition was not available. In the spectra, the dash (-) is replaced with a question mark (?). Peaks that are not assigned are most likely real features and not noise but cannot be confidently assigned to a transition without further investigation. Several peaks have multiple assignments due to limited resolution of the spectrometer used (20,000, $\lambda/\Delta\lambda$) and without the availability, at this point in time, of pure PuO_2 , AmO_2 , and NpO_2 to confirm the identity of the peaks. A different spectrometer was used in the plutonium facility to collect the mixed actinide fuel pellet data (Echelle 3000) than the DUO_2 , ThO_2 and uranium ore previously reported [6-8] (Echelle 4000) which accounts for the slight shift in the observed wavelength of the uranium emission lines.

Experimental:

The LIBS spectra were obtained by focusing the output from a Nd:YAG laser beam, operating at 20 Hz, onto the surface of a mixed actinide fuel pellet, a cylindrical rod approximately 3 mm in length and 1.5 mm in diameter, containing 75% UO_2 / 20% PuO_2 / 3% AmO_2 / 2% NpO_2 . The average of 200 spectra is presented here. The measurement parameters are listed in Table 1.

Acknowledgments:

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References:

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Table 1. Measurement parameters used to record the thorium atomic emission spectra.

Laser.....	Quantel USA, Ultra 100, 1064 nm, Gaussian beam profile, 8-60 mJ/pulse ~7 ns pulse width, 20 Hz repetition rate
Spectrometer.....	LLA Instruments, Echelle ESA 3000 Spectrometer, Spectral range 200-780 nm, Resolution 20,000
Detector.....	CCD-Array Kodak KAF-1001 (1024x1024 pixel) Gated Microchannel Plate (MCP), double correlated sampling, frame-grabber, 16-bit ADU, fast pulse-generator, MCP gated from 20 ns – 16 seconds (Gate Width = 20 μ s and Gate Delay = 1 μ s were used for this experiment)
Light Collection Optics.....	5 meter fiber optic cable
Laser Pulse Focusing Lens.....	Spherical, 25 mm diameter, Focal length: 4 inches, Lens to sample distance: 4 inches

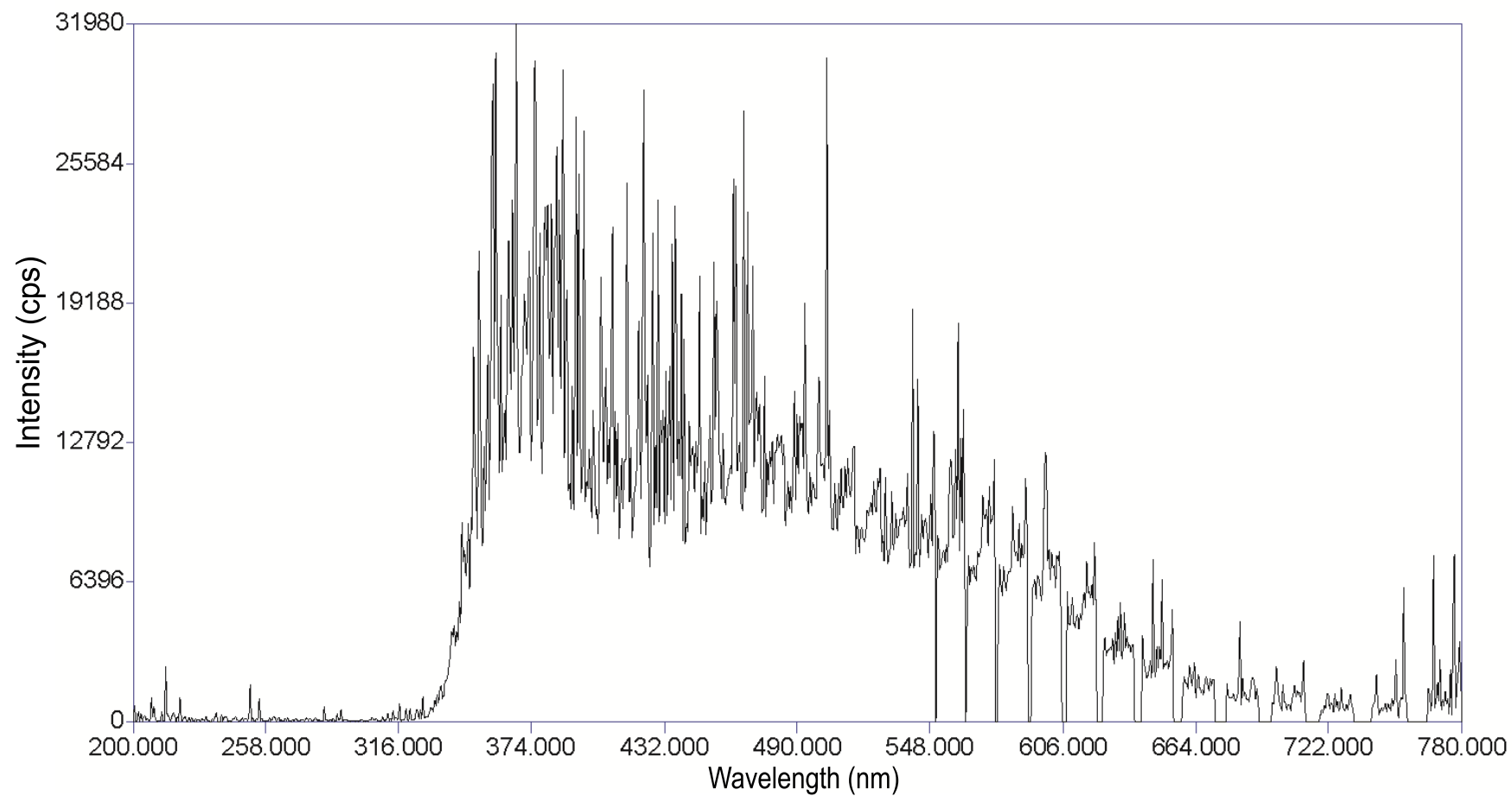
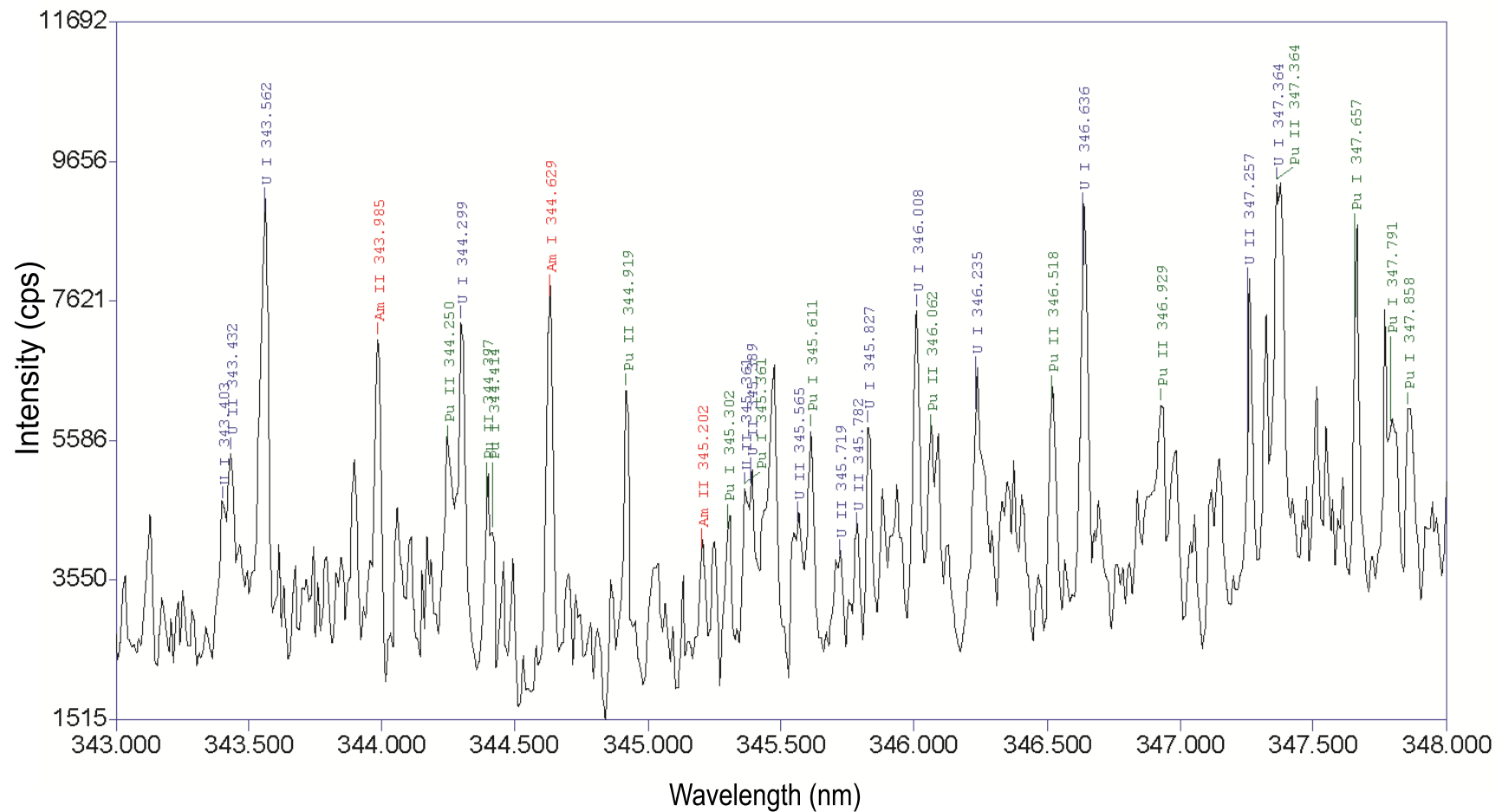


Figure 1 – Mixed Actinide Fuel Pellet (200 – 780 nm).



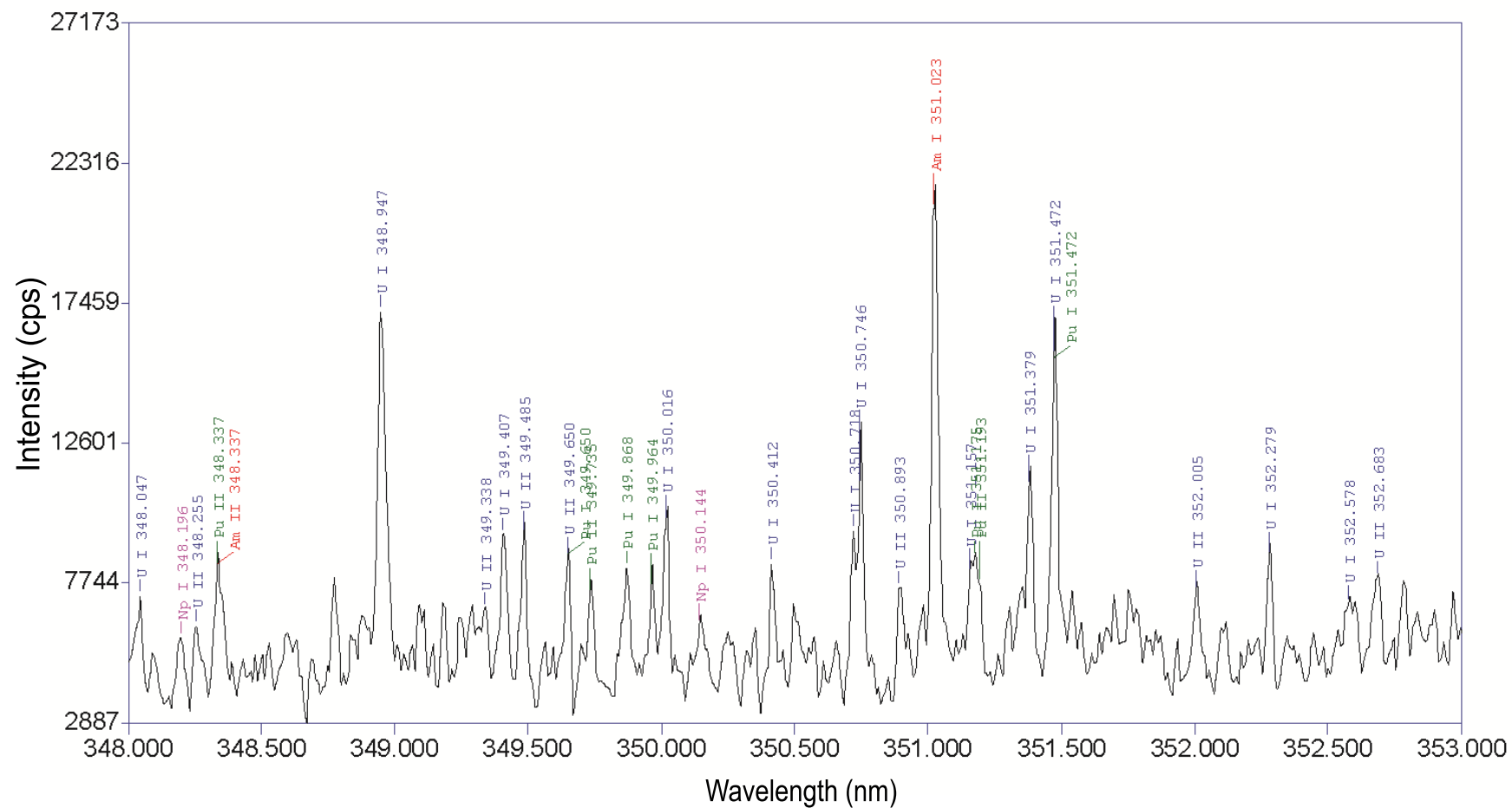


Figure 3 – Mixed Actinide Fuel Pellet (348 – 353 nm).

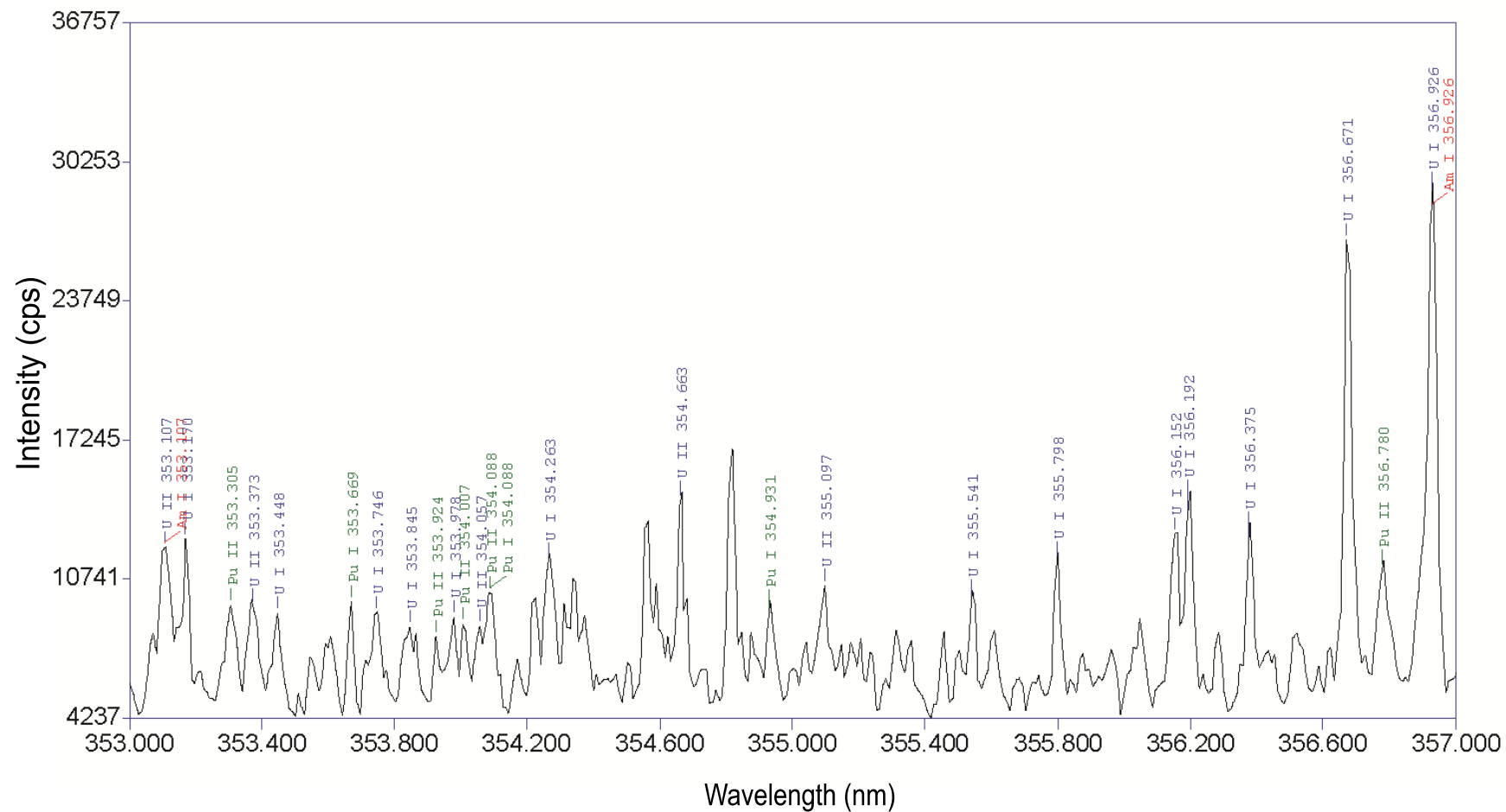


Figure 4 – Mixed Actinide Fuel Pellet (353 – 357 nm).

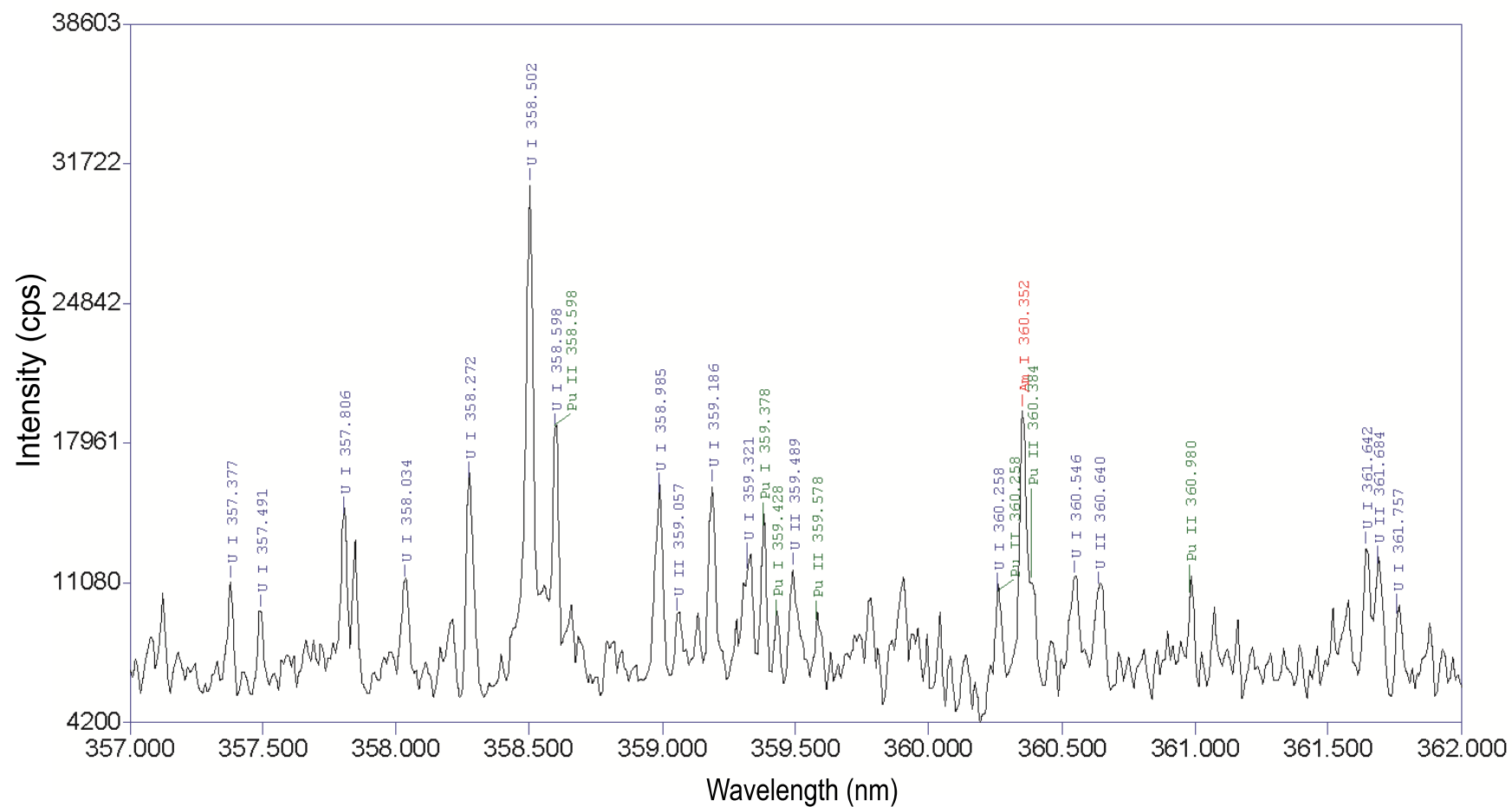


Figure 5 – Mixed Actinide Fuel Pellet (357 – 362 nm).

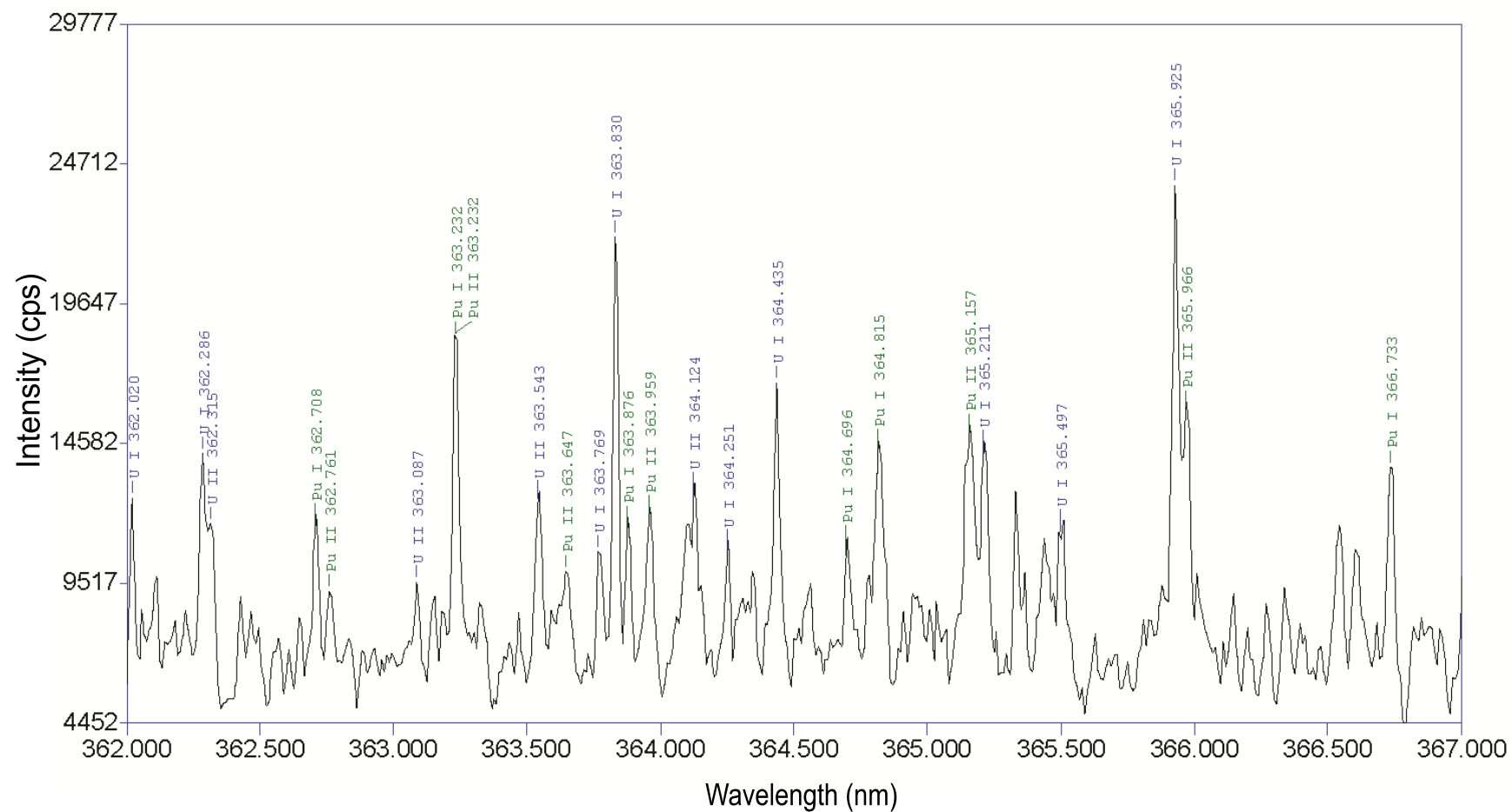


Figure 6 – Mixed Actinide Fuel Pellet (362 – 367 nm).

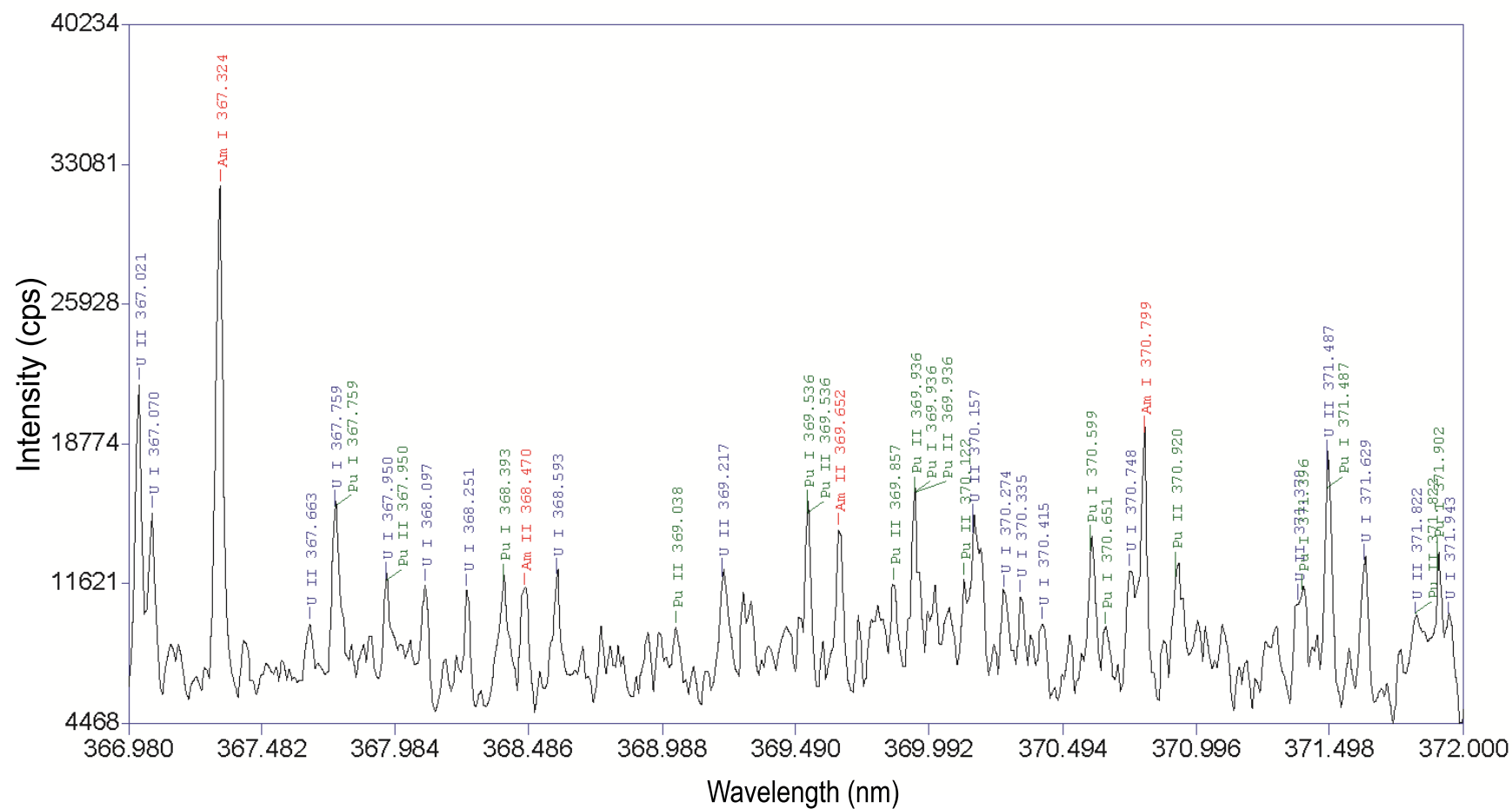


Figure 7 – Mixed Actinide Fuel Pellet (367 – 372 nm).

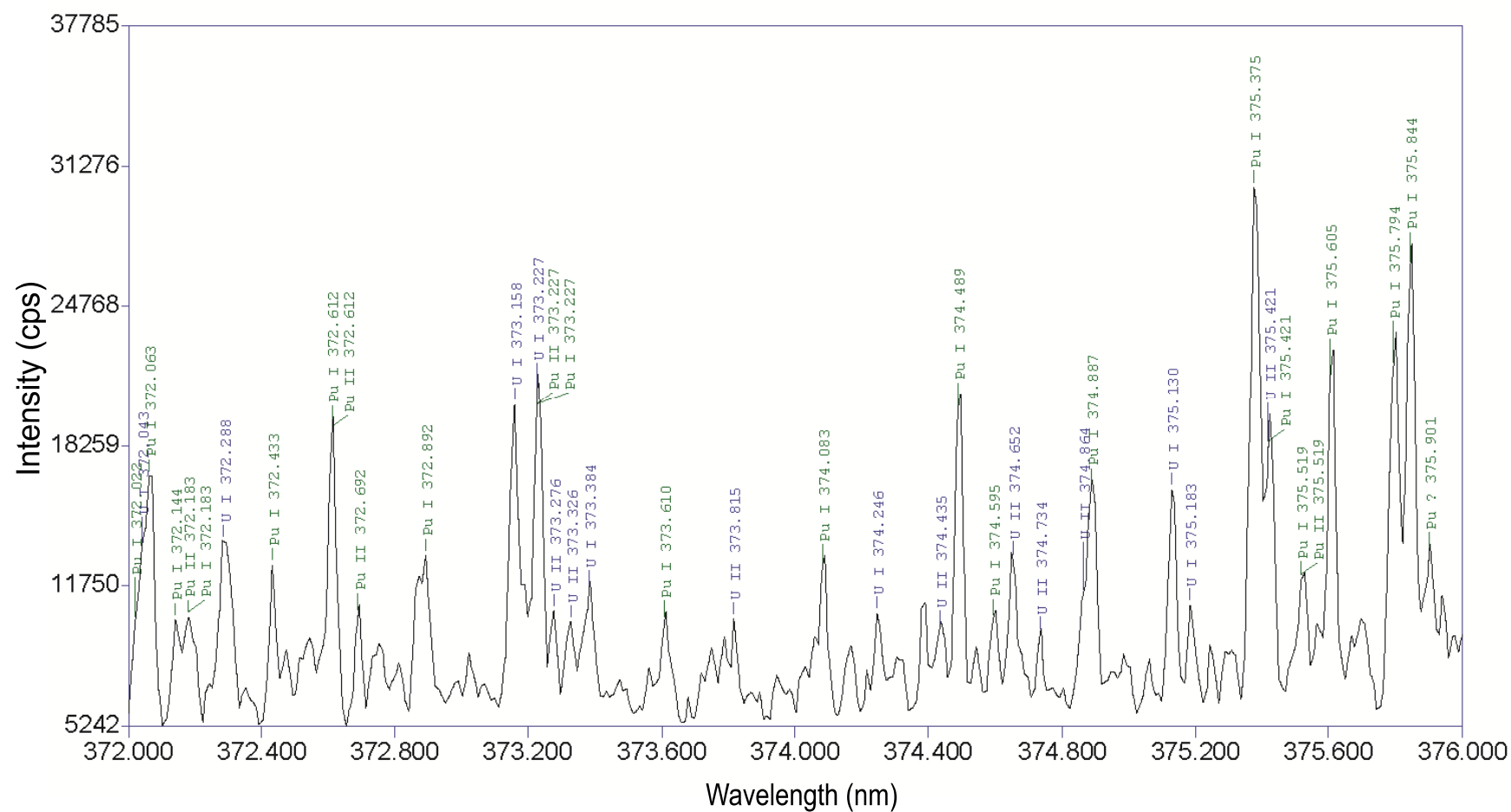


Figure 8 – Mixed Actinide Fuel Pellet (372 – 376 nm).

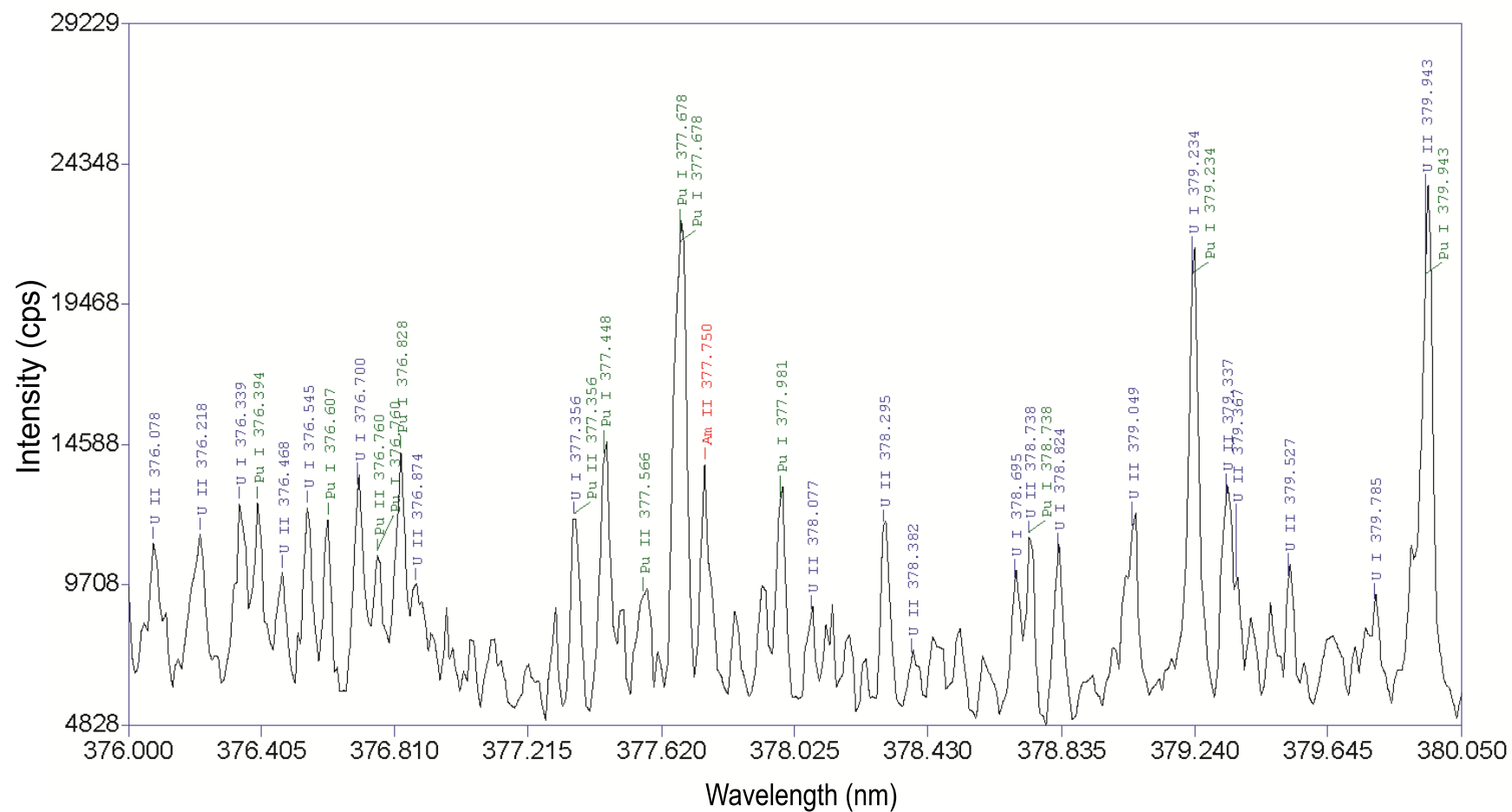


Figure 9 – Mixed Actinide Fuel Pellet (376 – 380 nm).

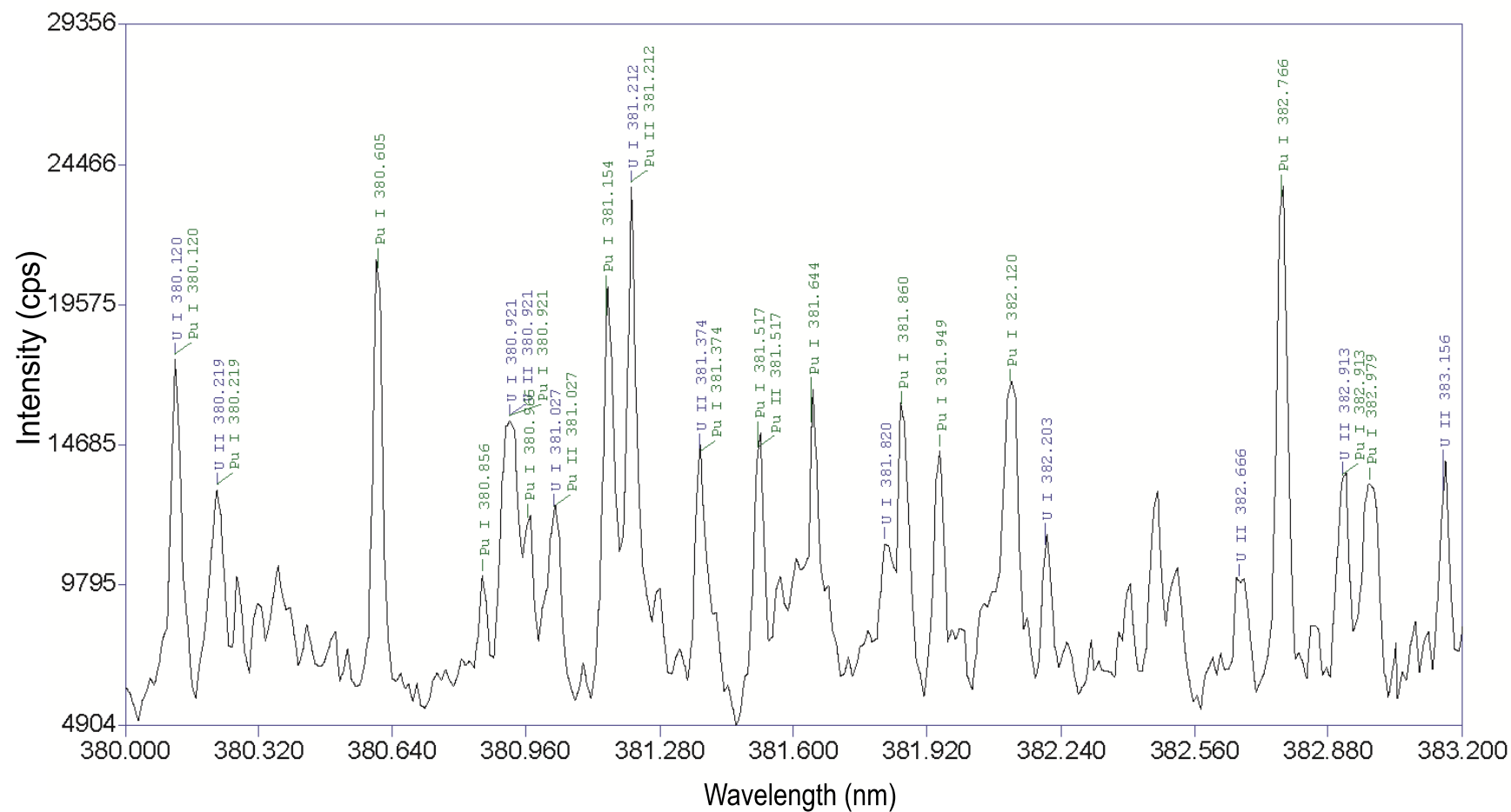


Figure 10 – Mixed Actinide Fuel Pellet (380 – 383 nm).

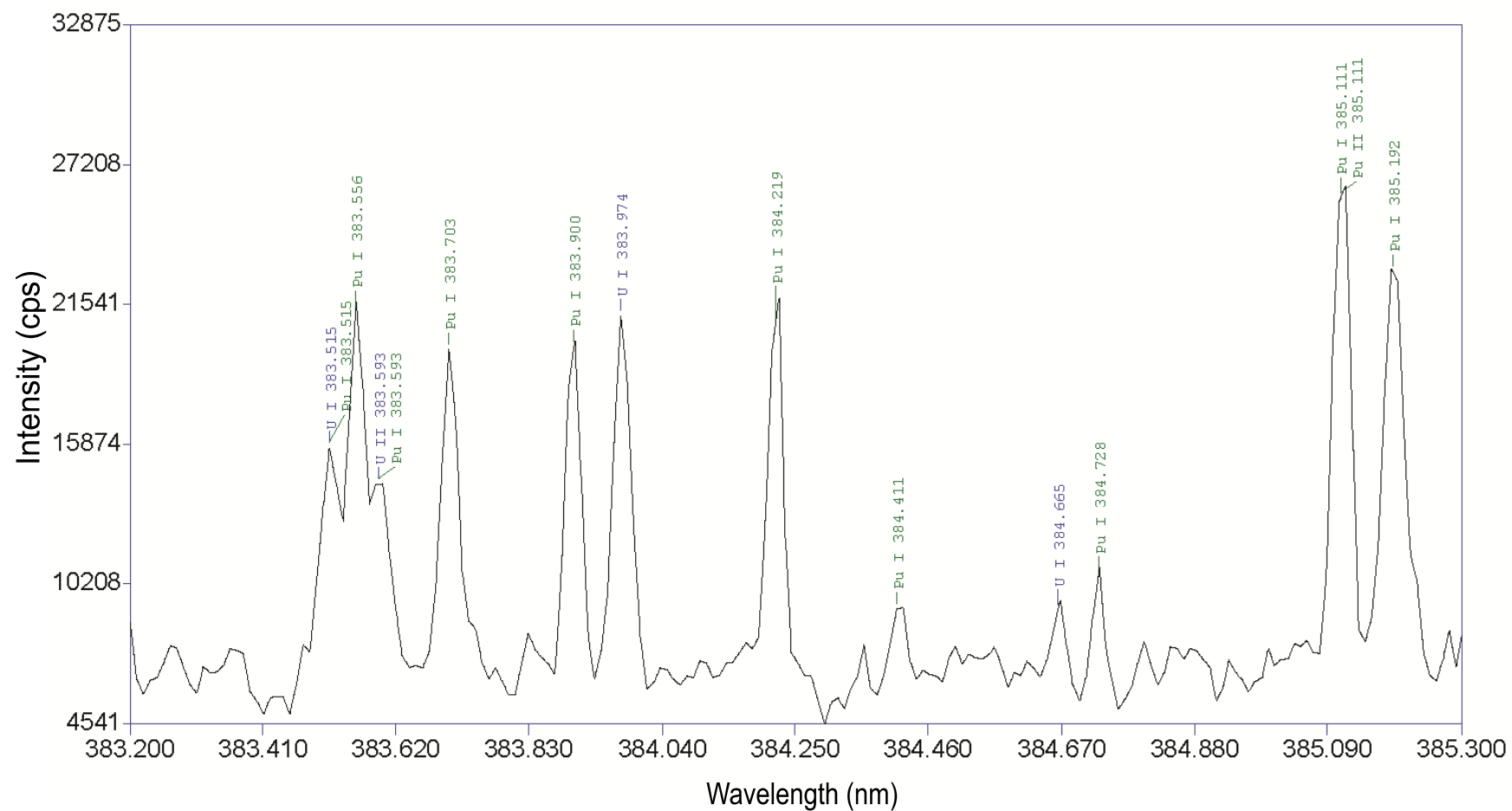


Figure 11 – Mixed Actinide Fuel Pellet (383 – 385 nm).

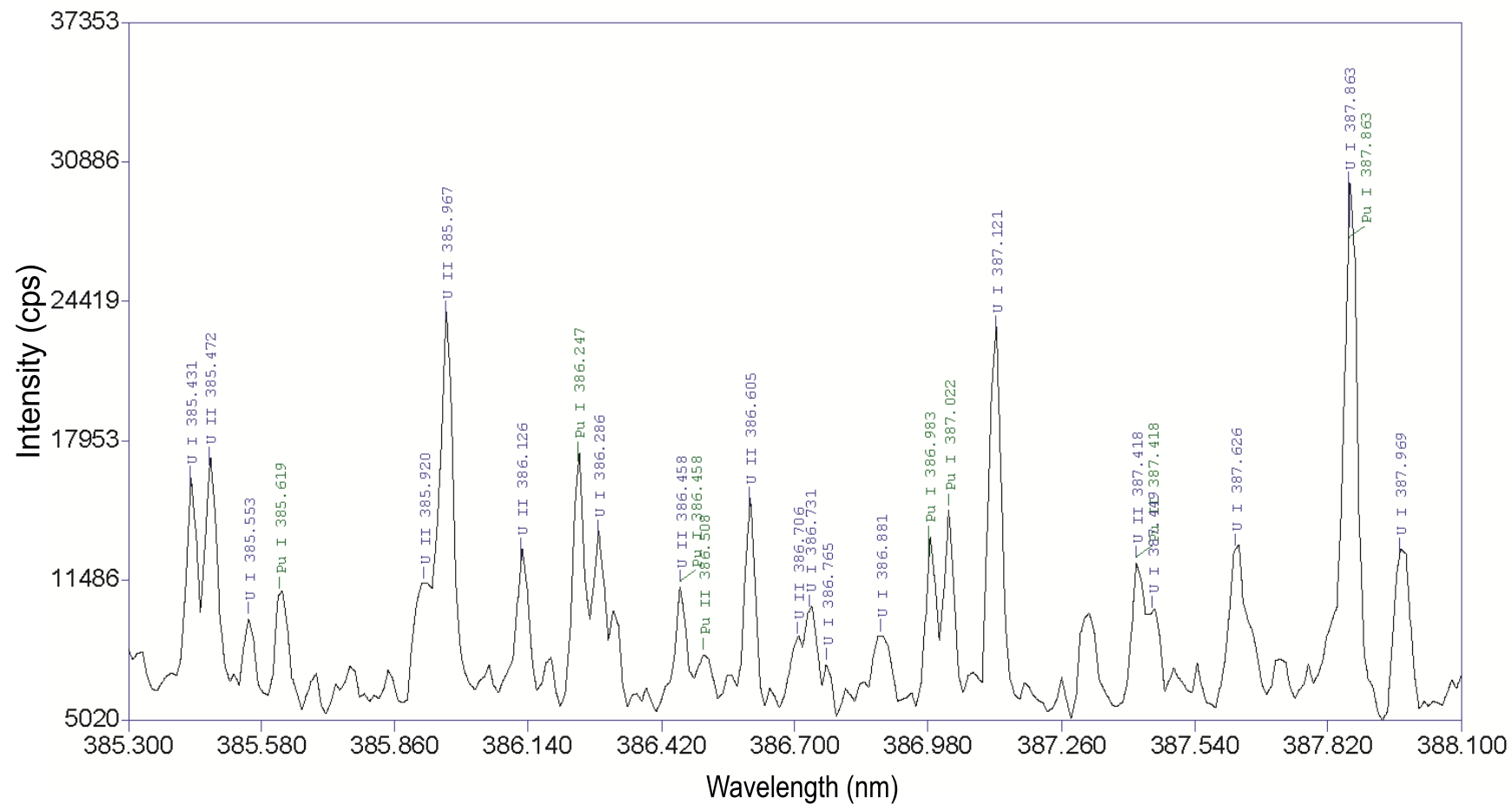


Figure 12 – Mixed Actinide Fuel Pellet (385 – 388 nm).

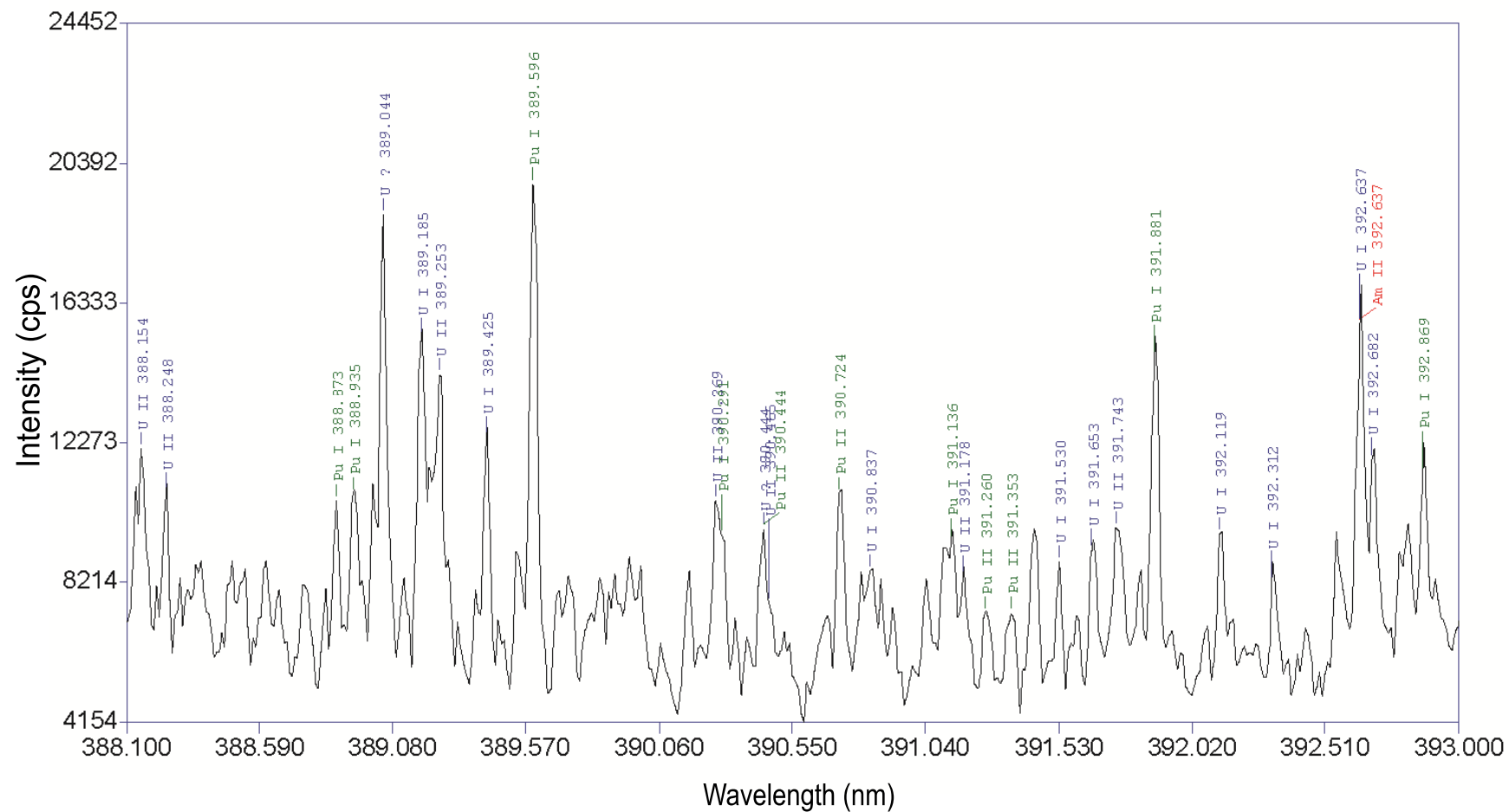


Figure 13 – Mixed Actinide Fuel Pellet (388 – 393 nm).

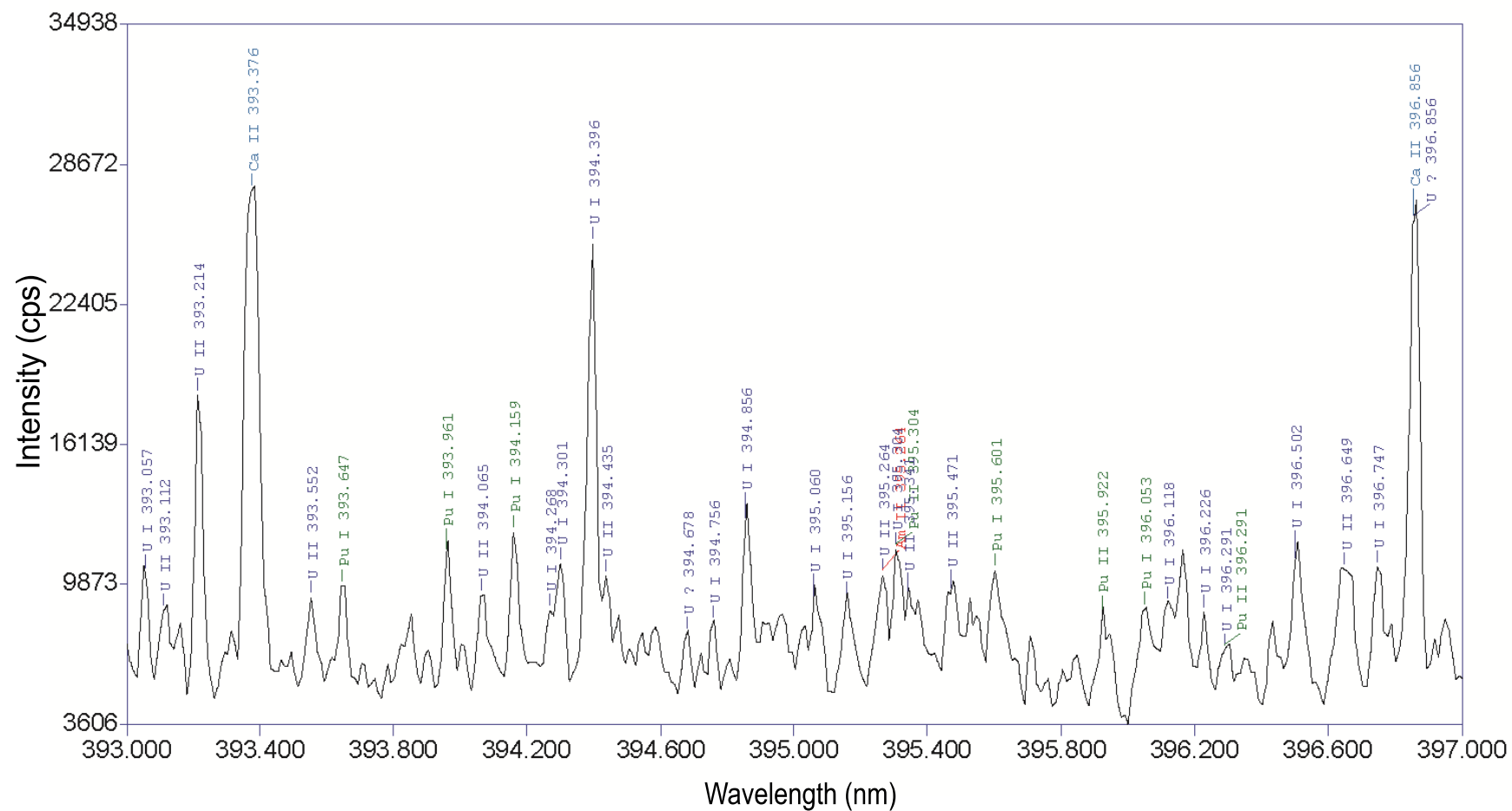


Figure 14 – Mixed Actinide Fuel Pellet (393 – 397 nm).

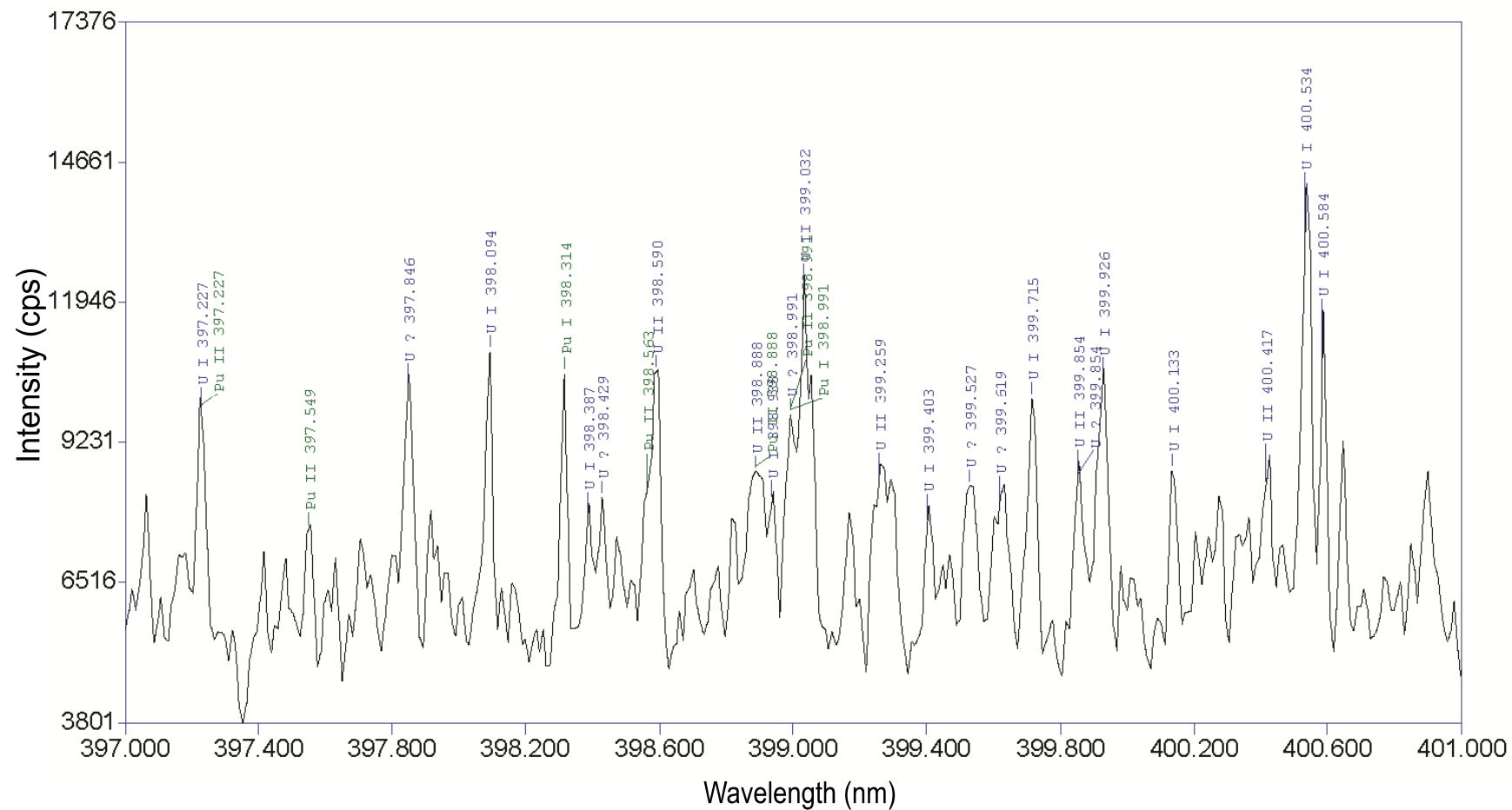


Figure 15 – Mixed Actinide Fuel Pellet (397 – 401 nm).

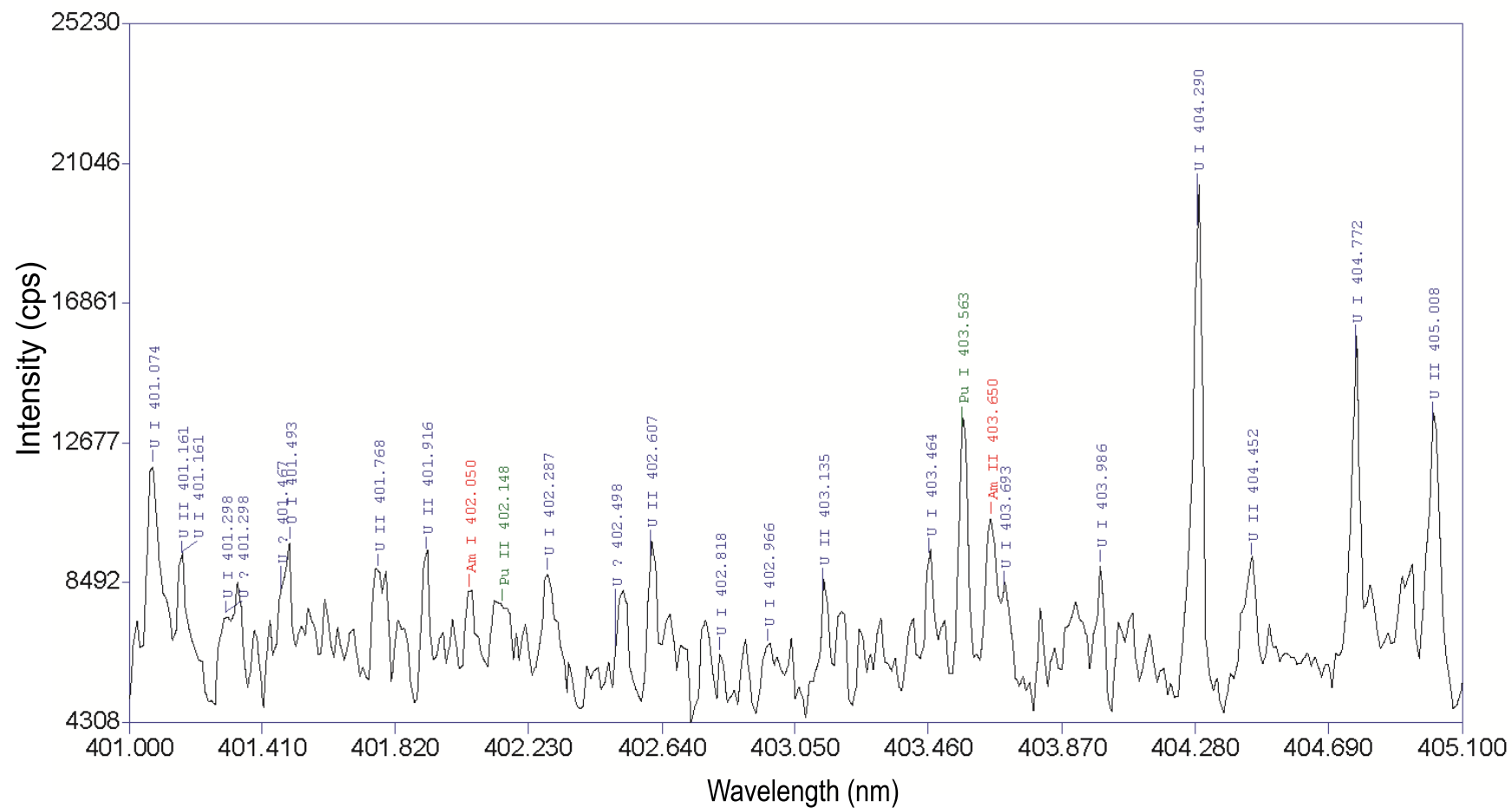


Figure 16 – Mixed Actinide Fuel Pellet (401 – 405 nm).

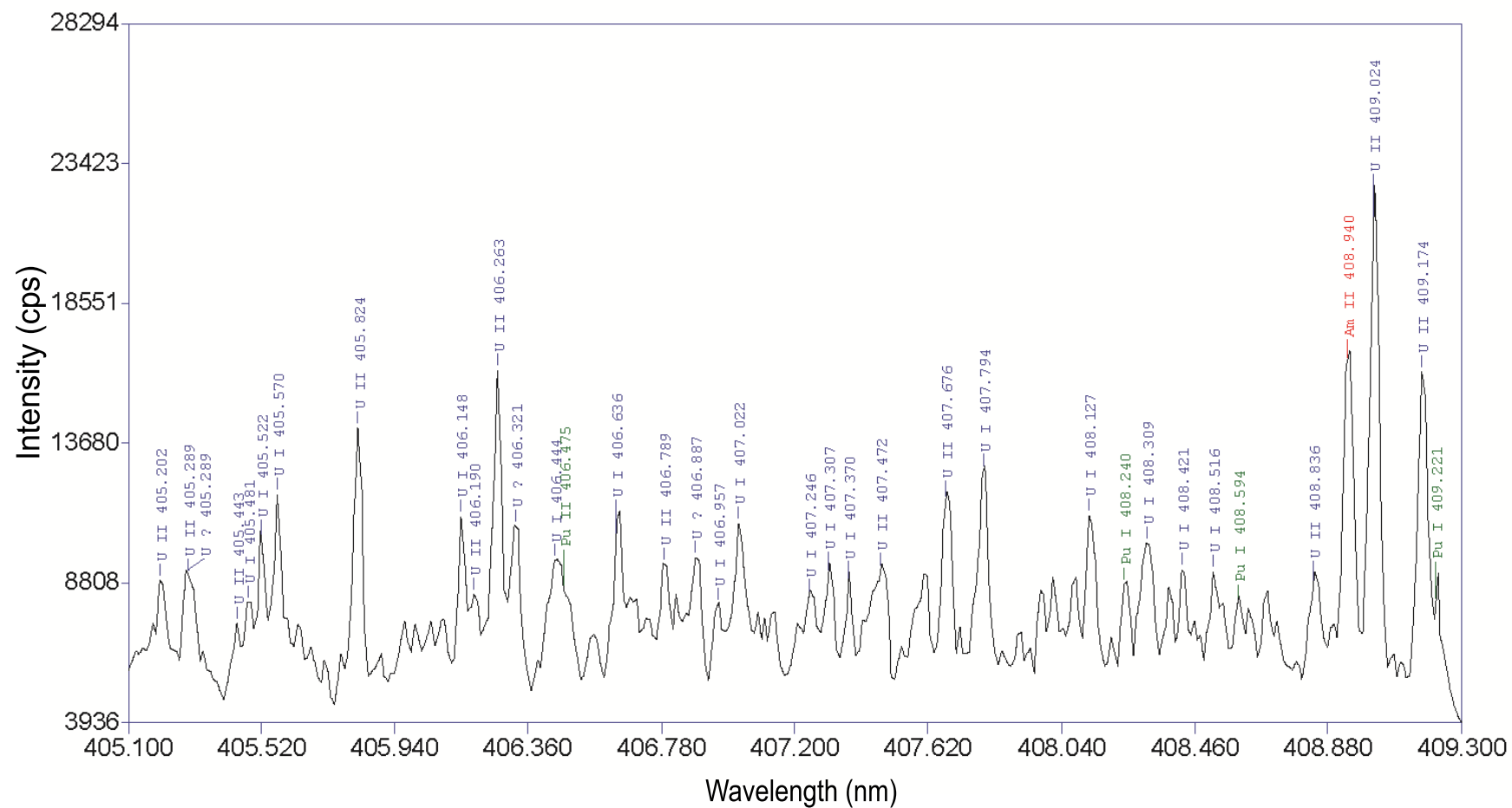


Figure 17 – Mixed Actinide Fuel Pellet (405 – 409 nm).

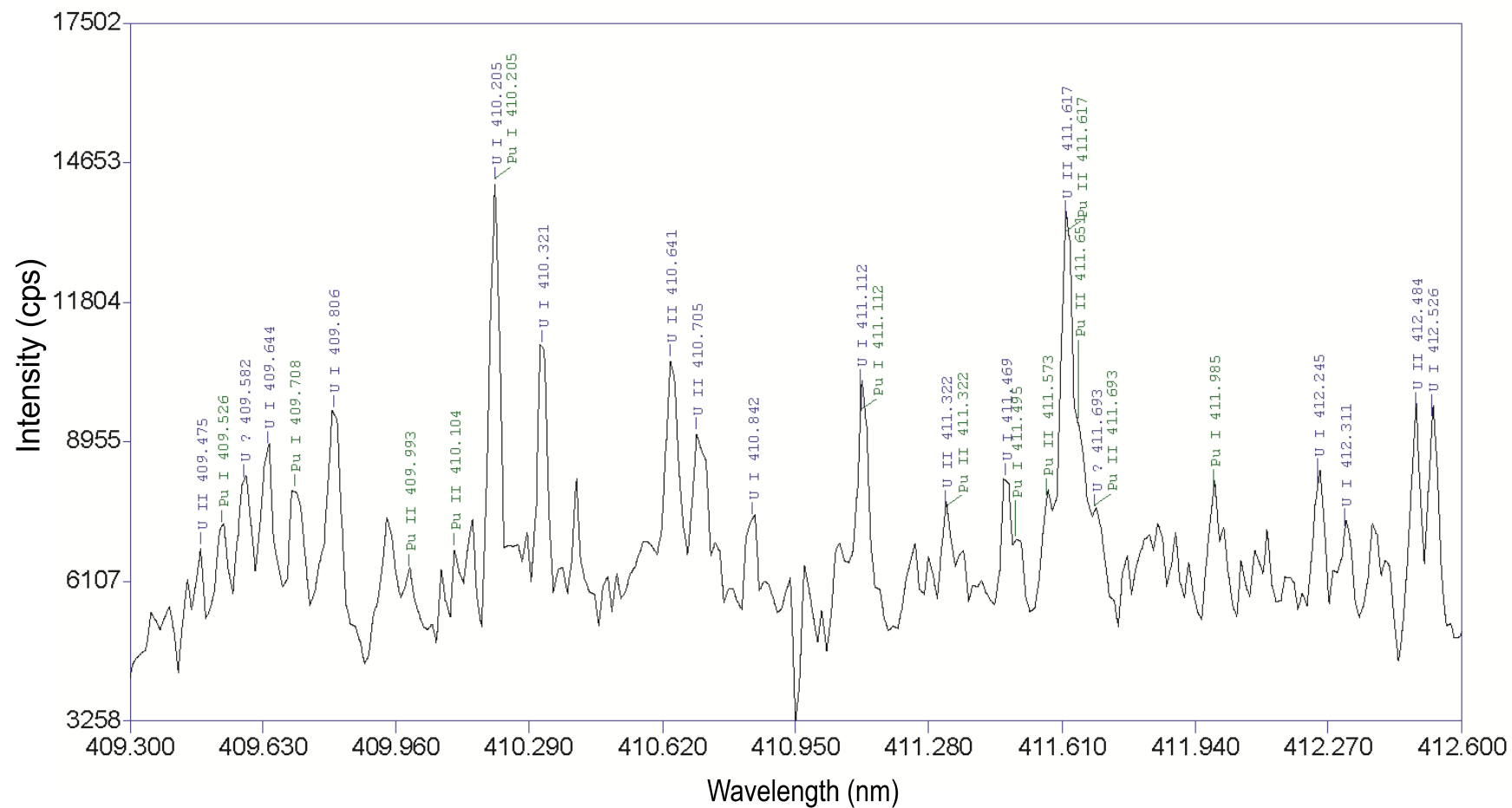


Figure 18 – Mixed Actinide Fuel Pellet (409 – 412 nm).

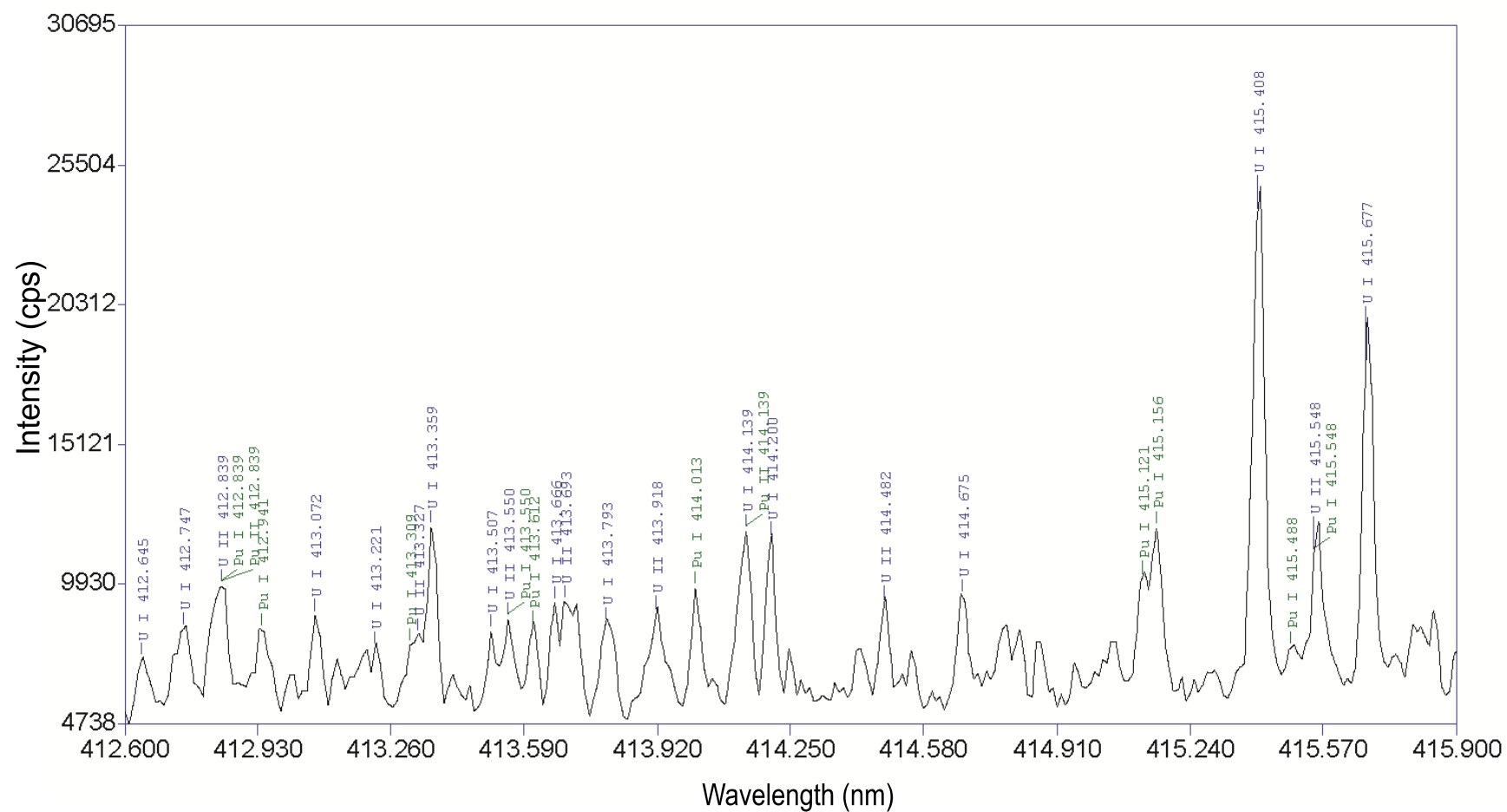


Figure 19 – Mixed Actinide Fuel Pellet (412 – 416 nm).

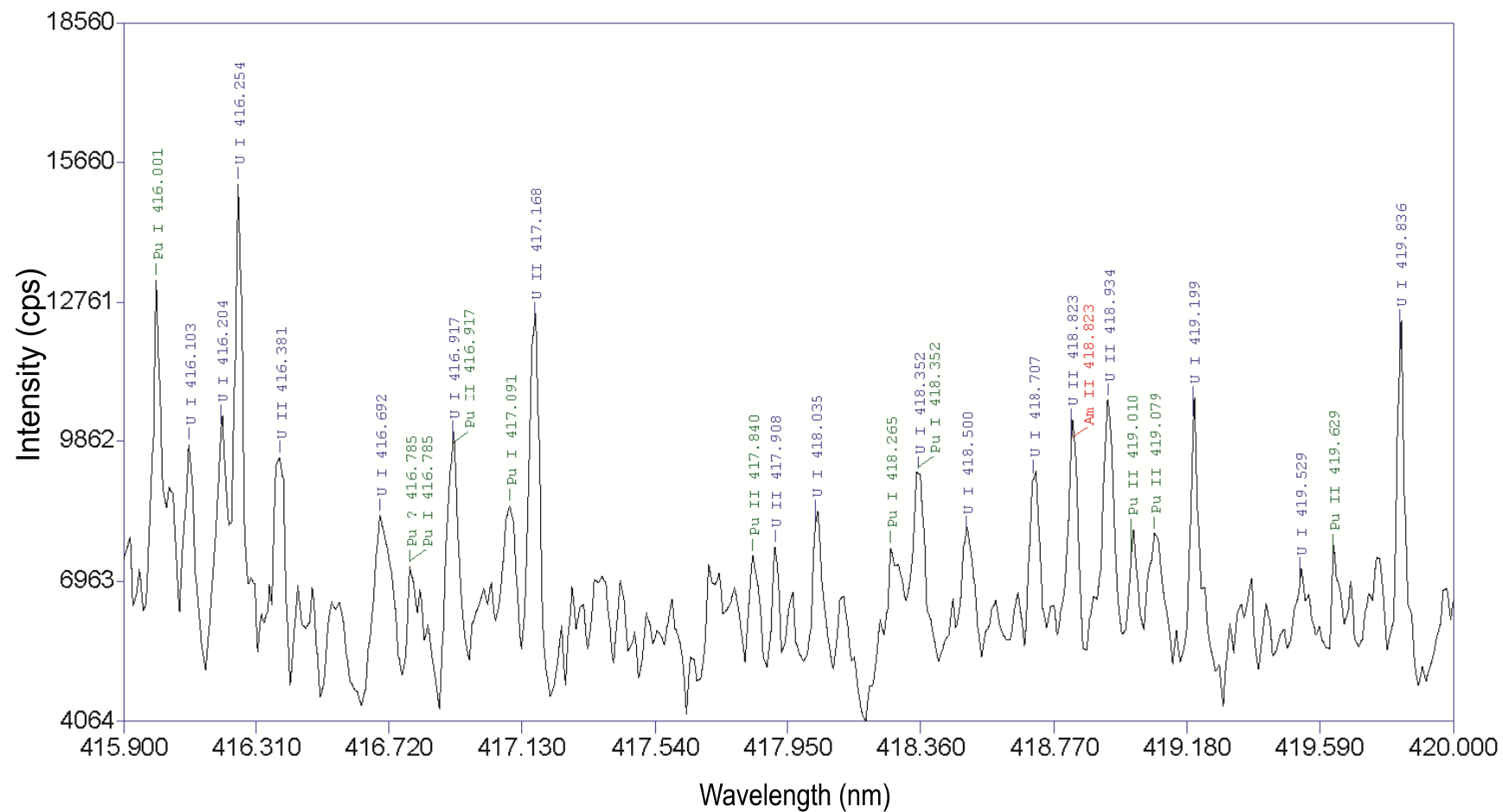


Figure 20 – Mixed Actinide Fuel Pellet (416 – 420 nm).

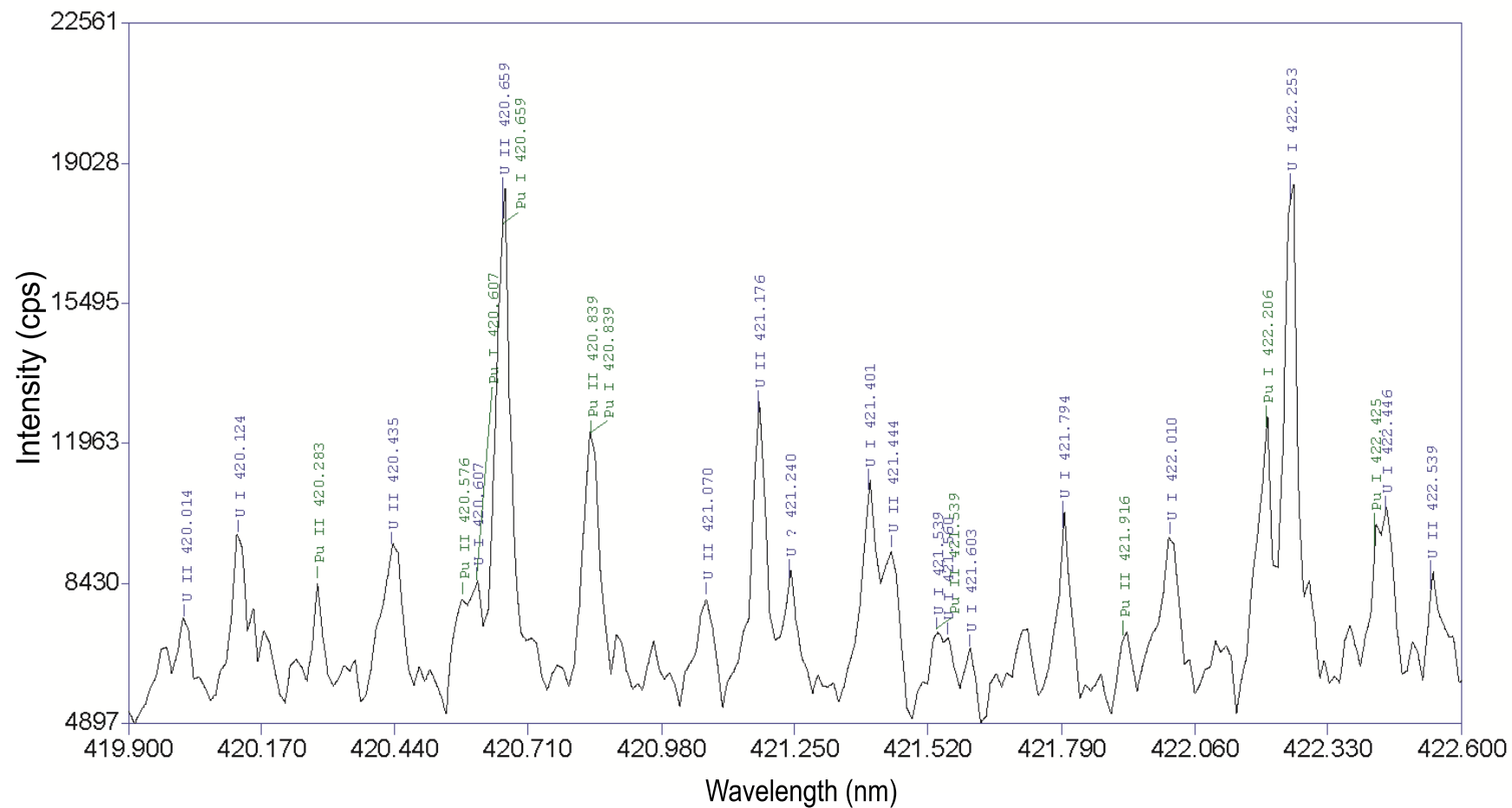


Figure 21 – Mixed Actinide Fuel Pellet (420 – 422 nm).

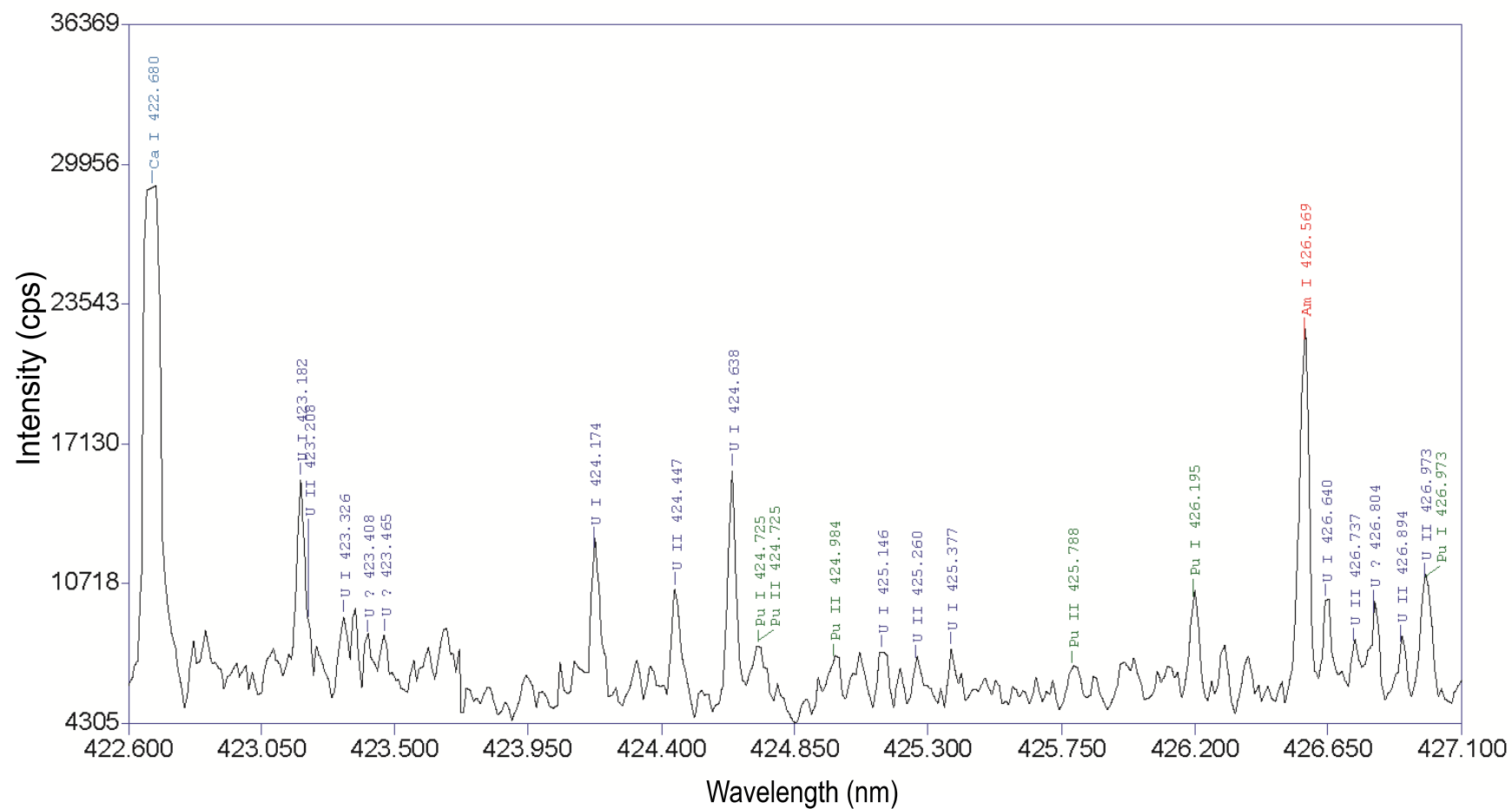


Figure 22 – Mixed Actinide Fuel Pellet (422 – 427 nm).

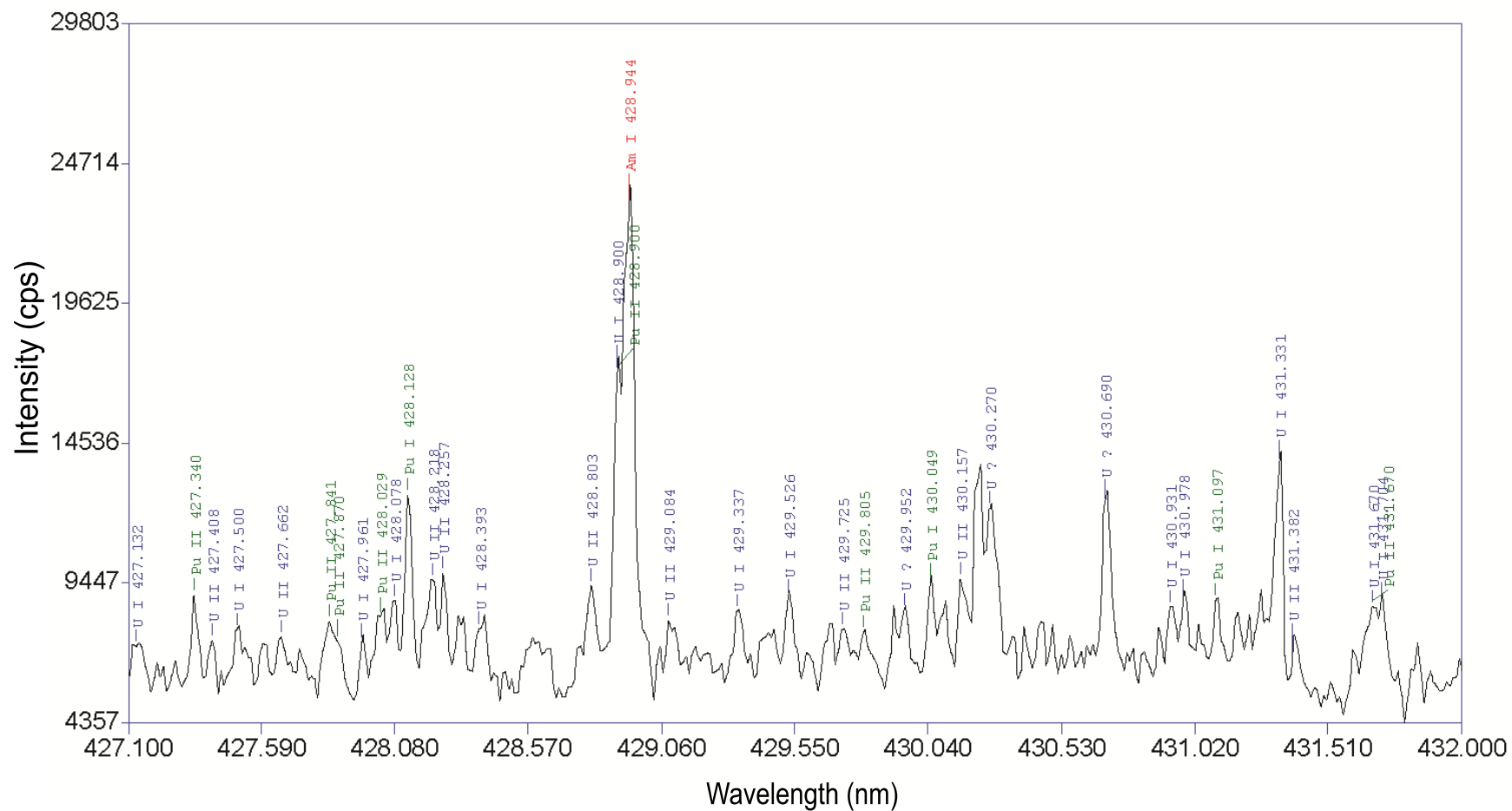


Figure 23 – Mixed Actinide Fuel Pellet (427 – 432 nm).

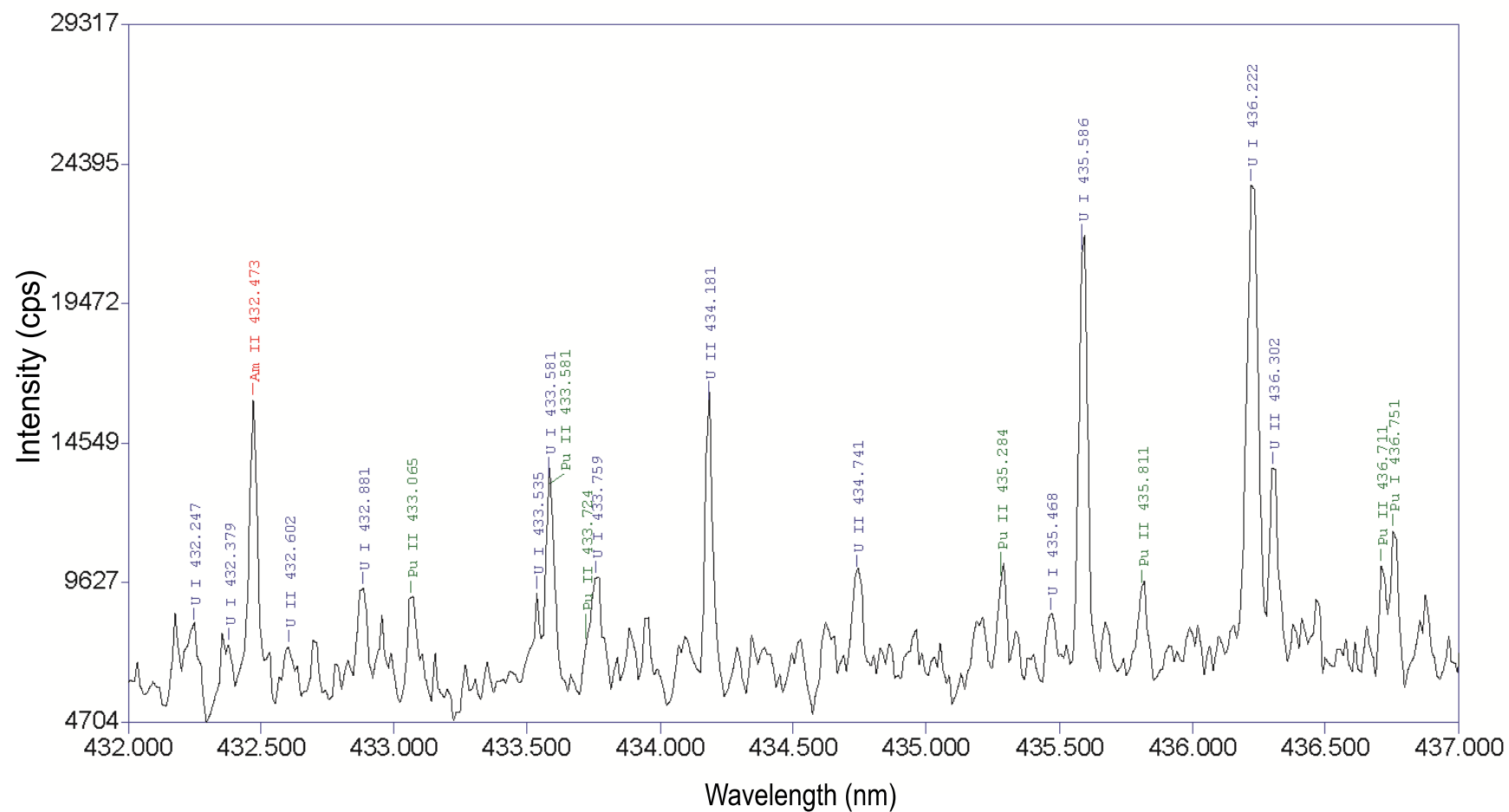


Figure 24 – Mixed Actinide Fuel Pellet (432 – 437 nm).

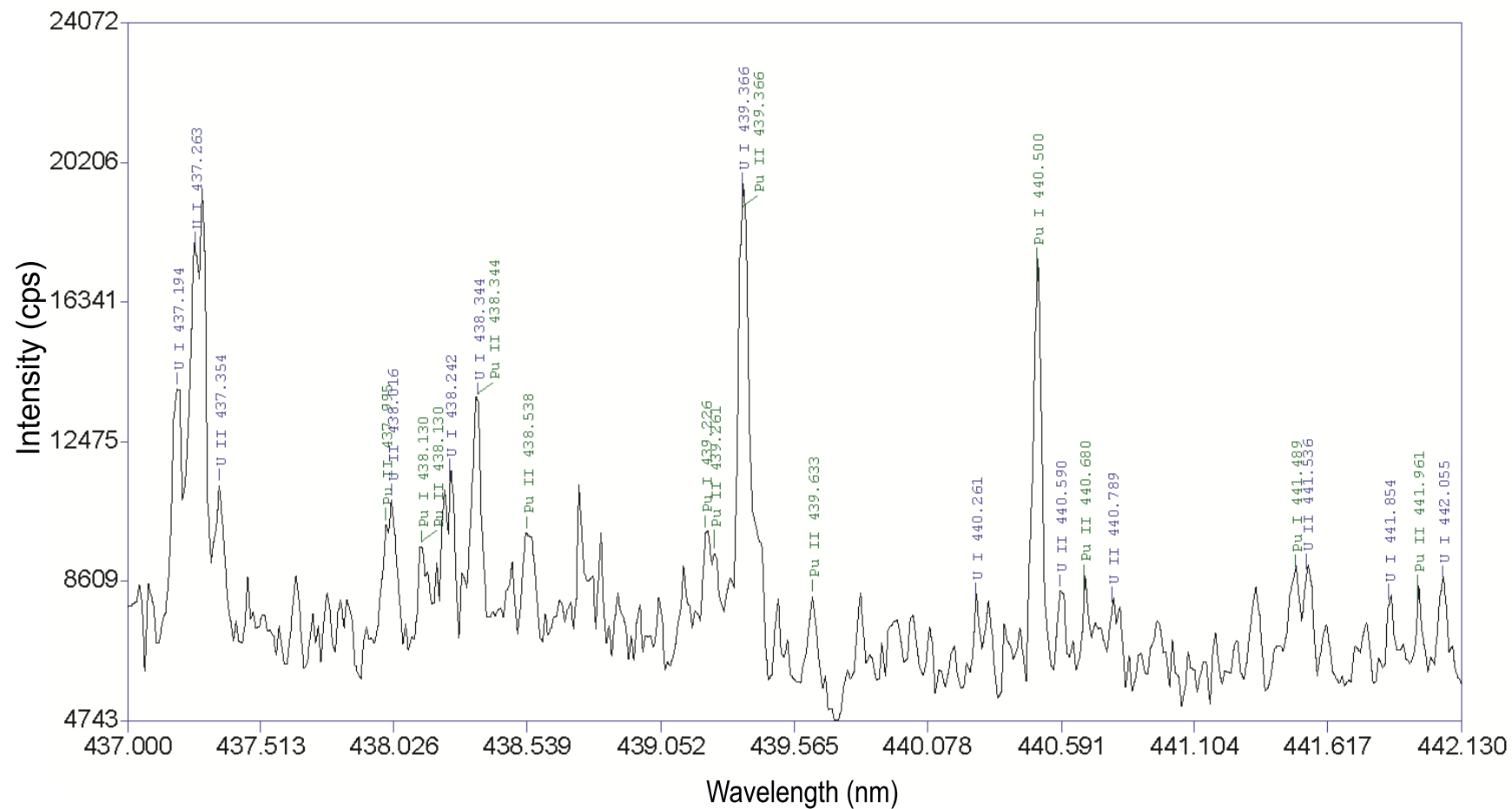


Figure 25 – Mixed Actinide Fuel Pellet (437 – 442 nm).

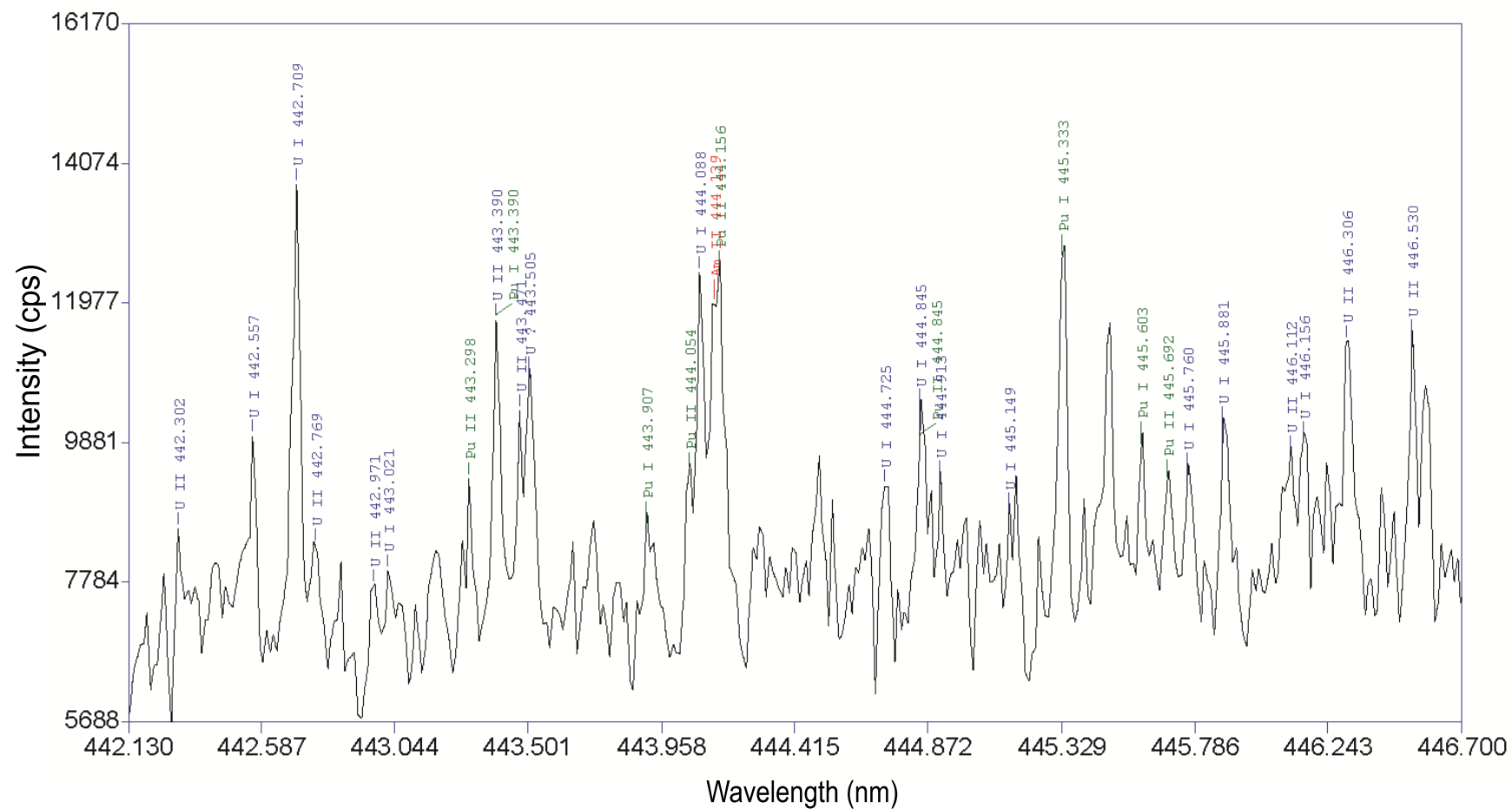


Figure 26 – Mixed Actinide Fuel Pellet (442 – 446 nm).

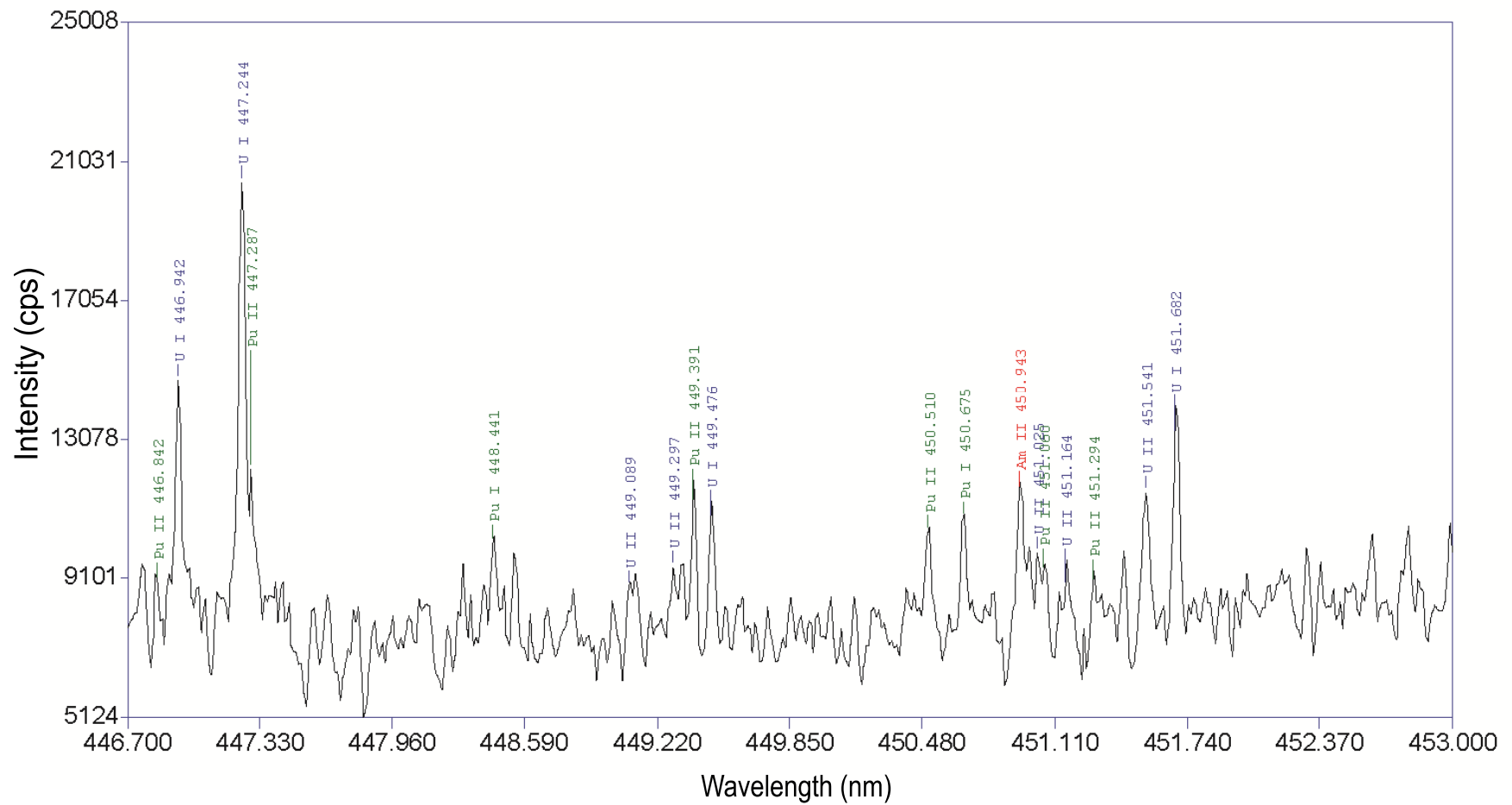


Figure 27 – Mixed Actinide Fuel Pellet (446 – 453 nm).

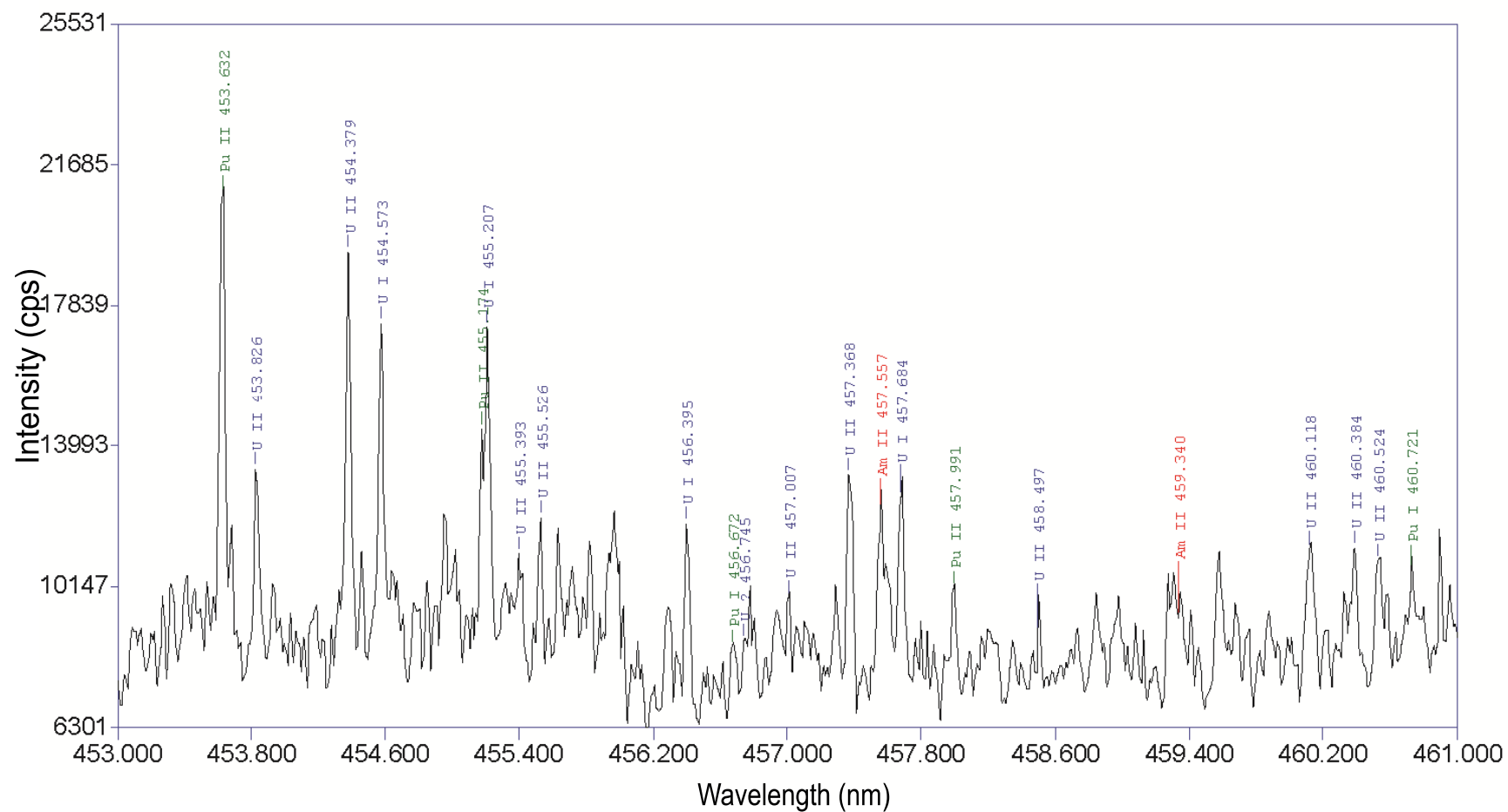


Figure 28 – Mixed Actinide Fuel Pellet (453 – 461 nm).

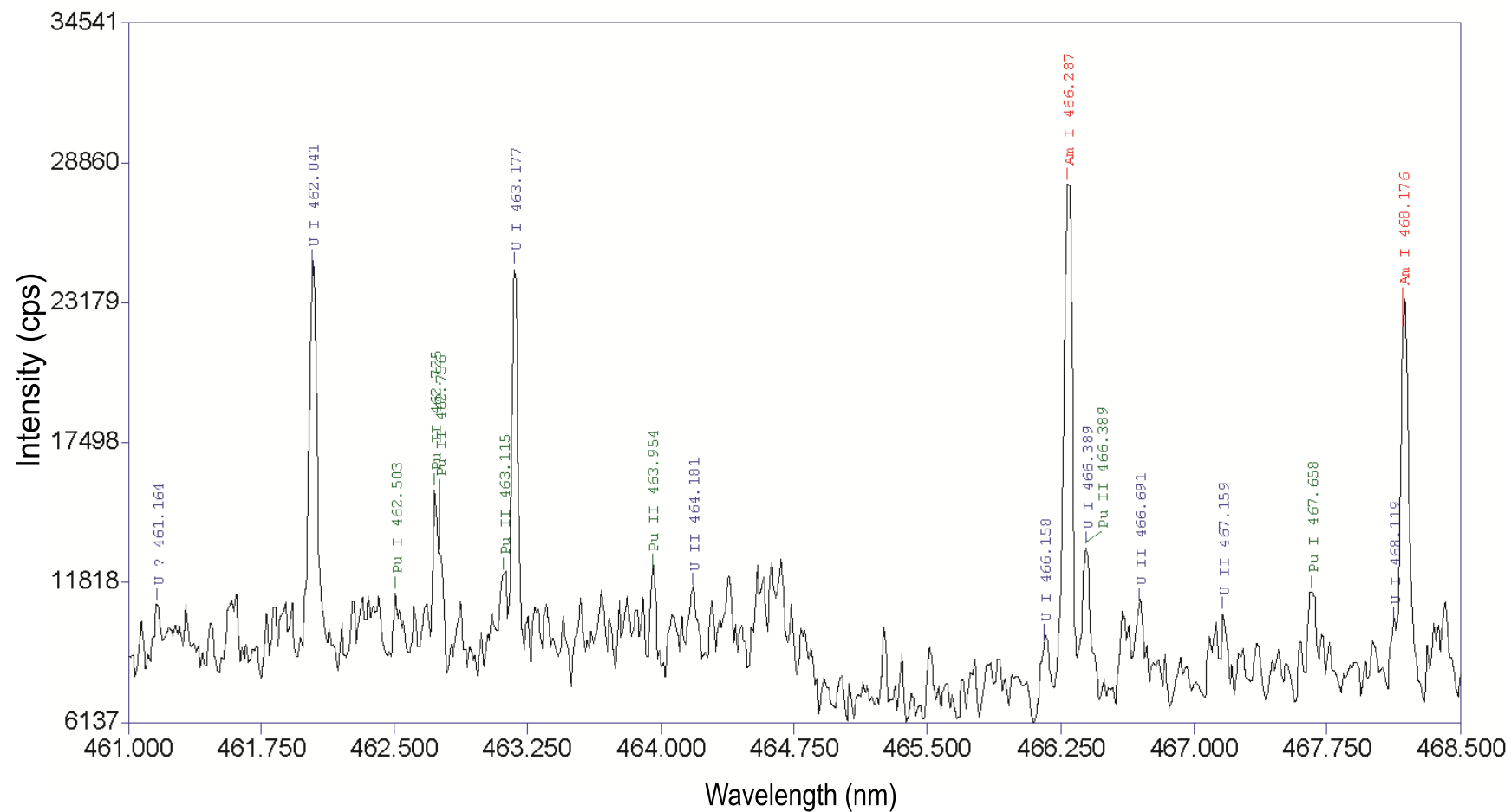


Figure 29 – Mixed Actinide Fuel Pellet (461 – 468 nm).

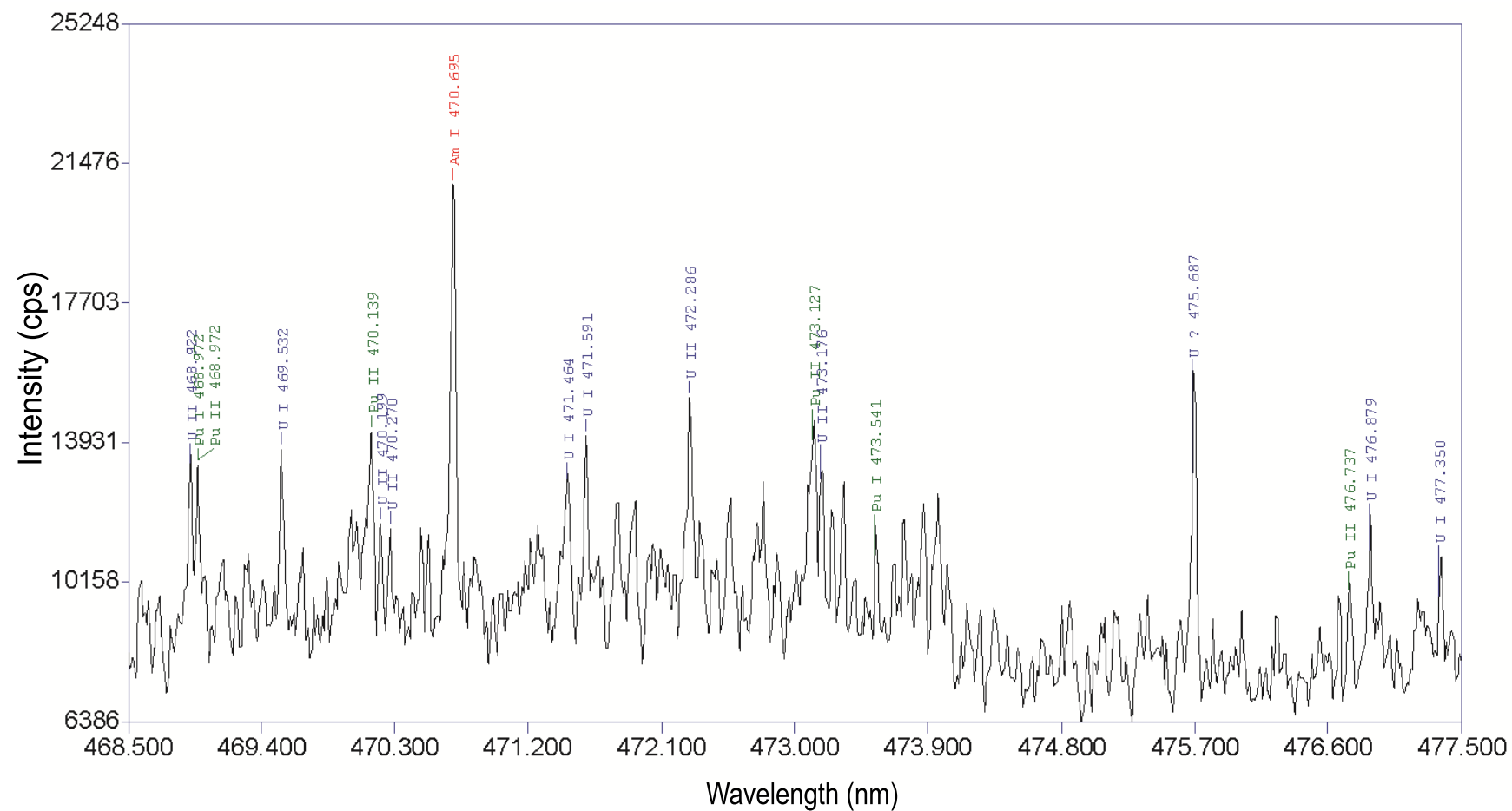


Figure 30 – Mixed Actinide Fuel Pellet (468 – 477 nm).

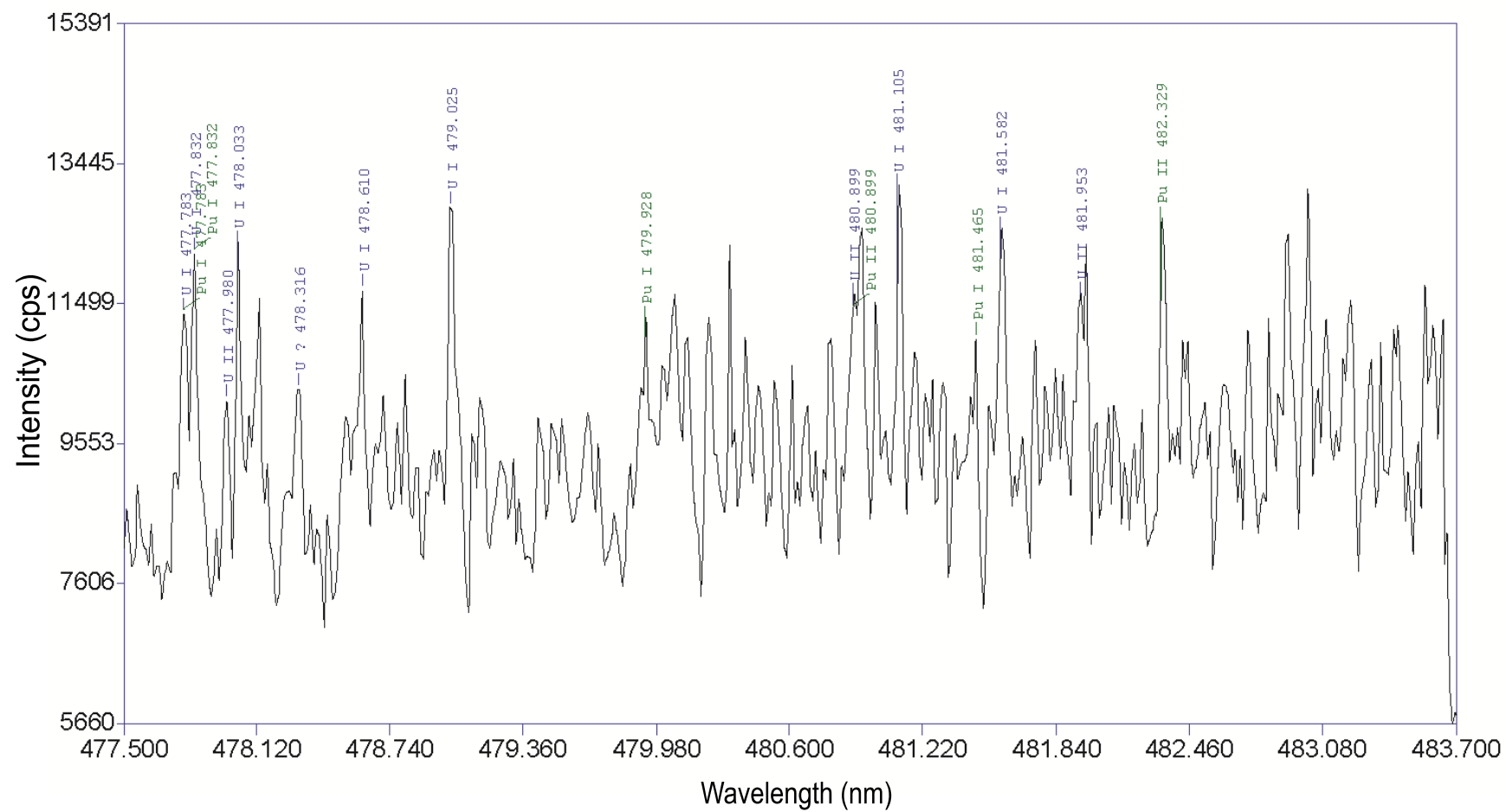


Figure 31 – Mixed Actinide Fuel Pellet (477 – 483 nm).

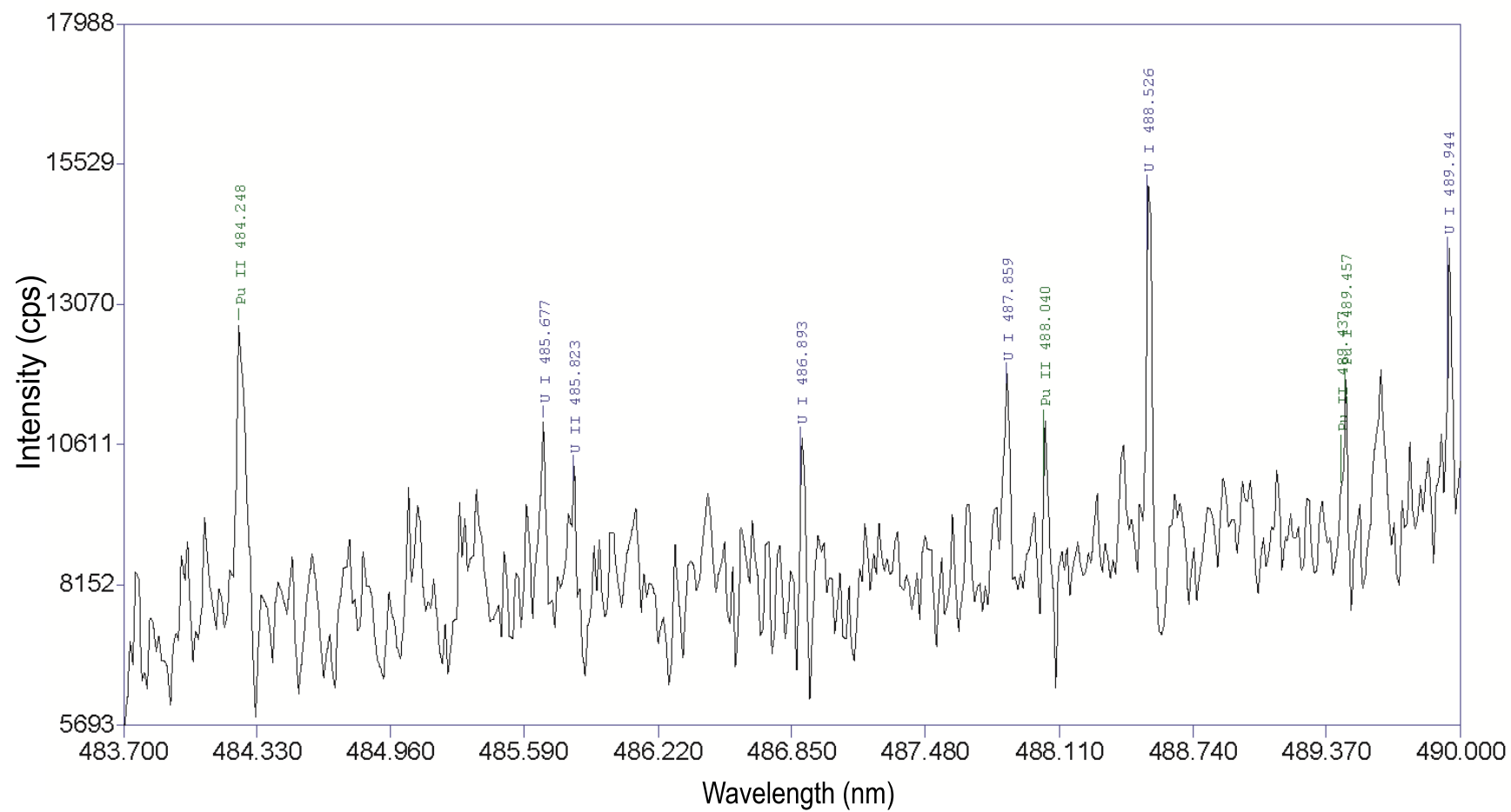


Figure 32 – Mixed Actinide Fuel Pellet (483 – 490 nm).

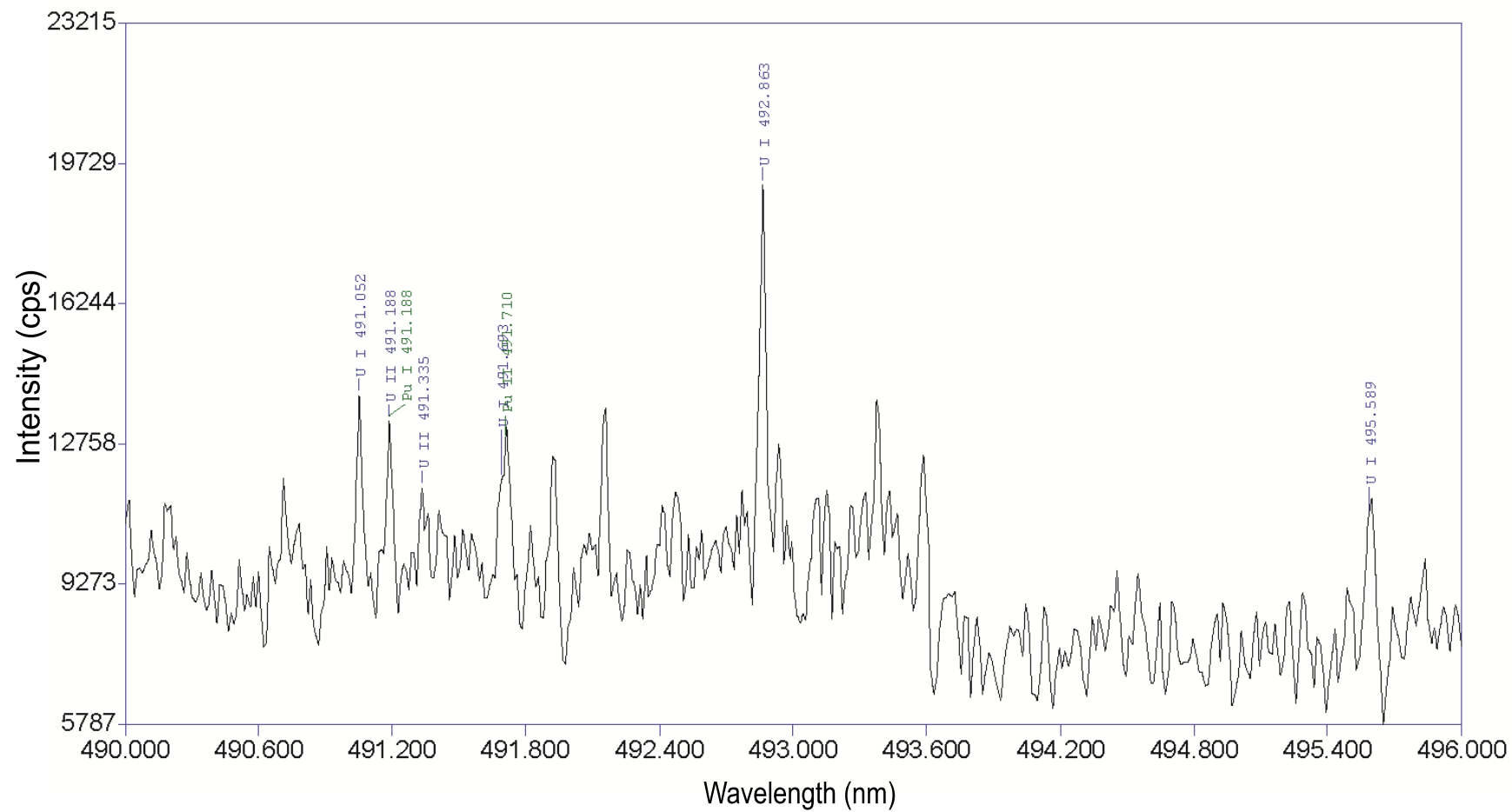


Figure 33 – Mixed Actinide Fuel Pellet (490 – 496 nm).

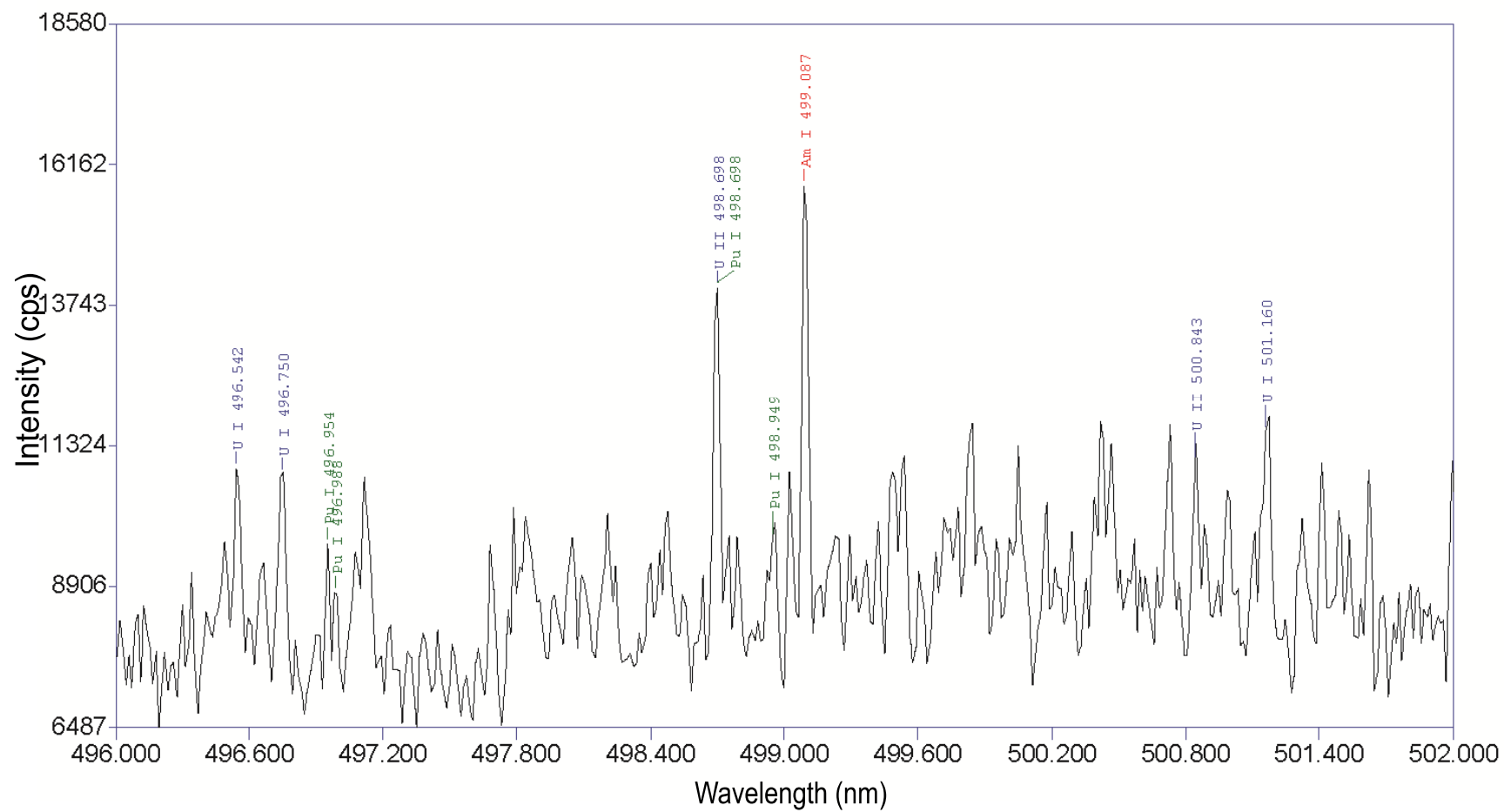


Figure 34 – Mixed Actinide Fuel Pellet (496 – 502 nm).

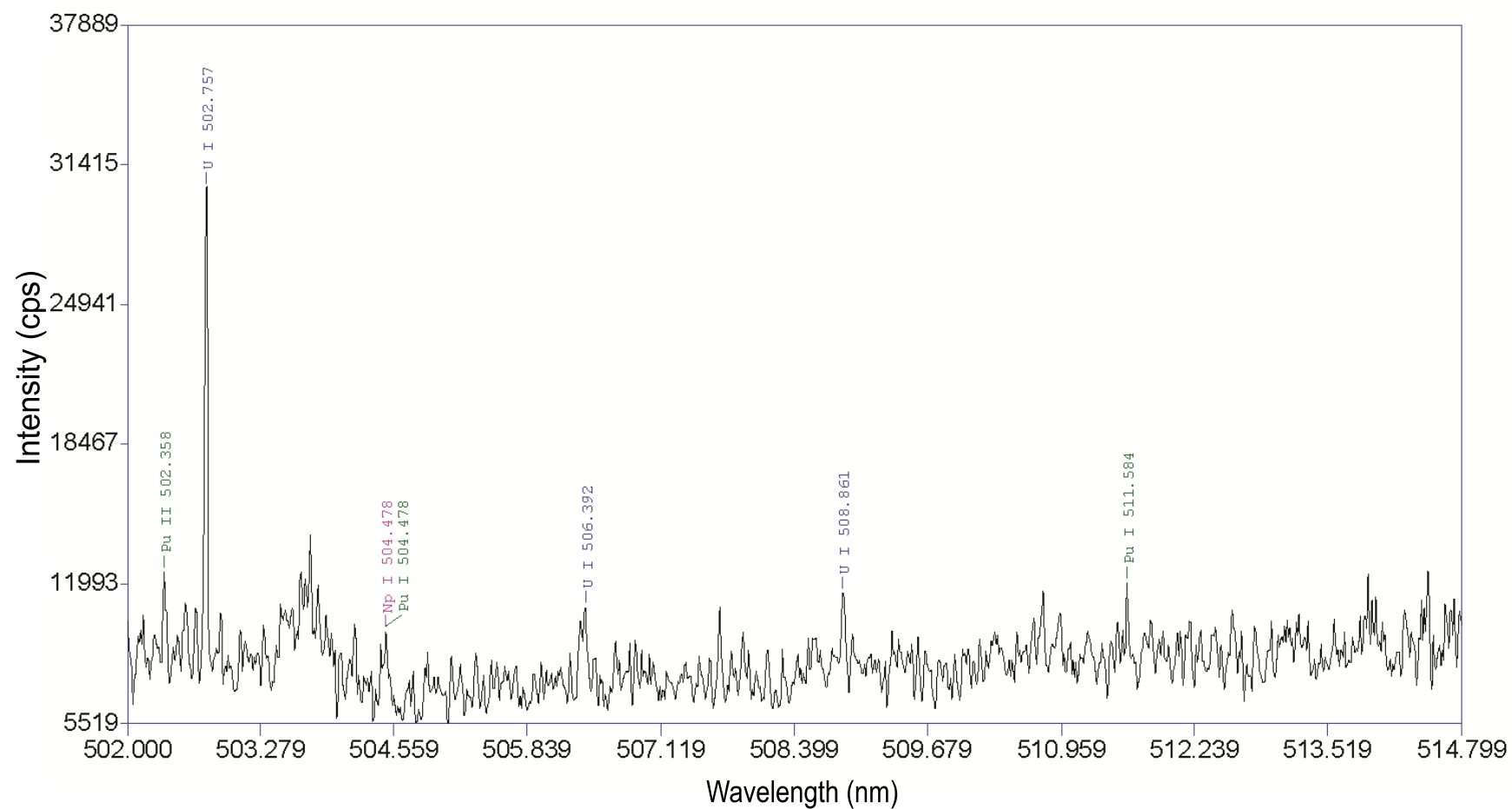


Figure 35 – Mixed Actinide Fuel Pellet (502 – 514 nm).

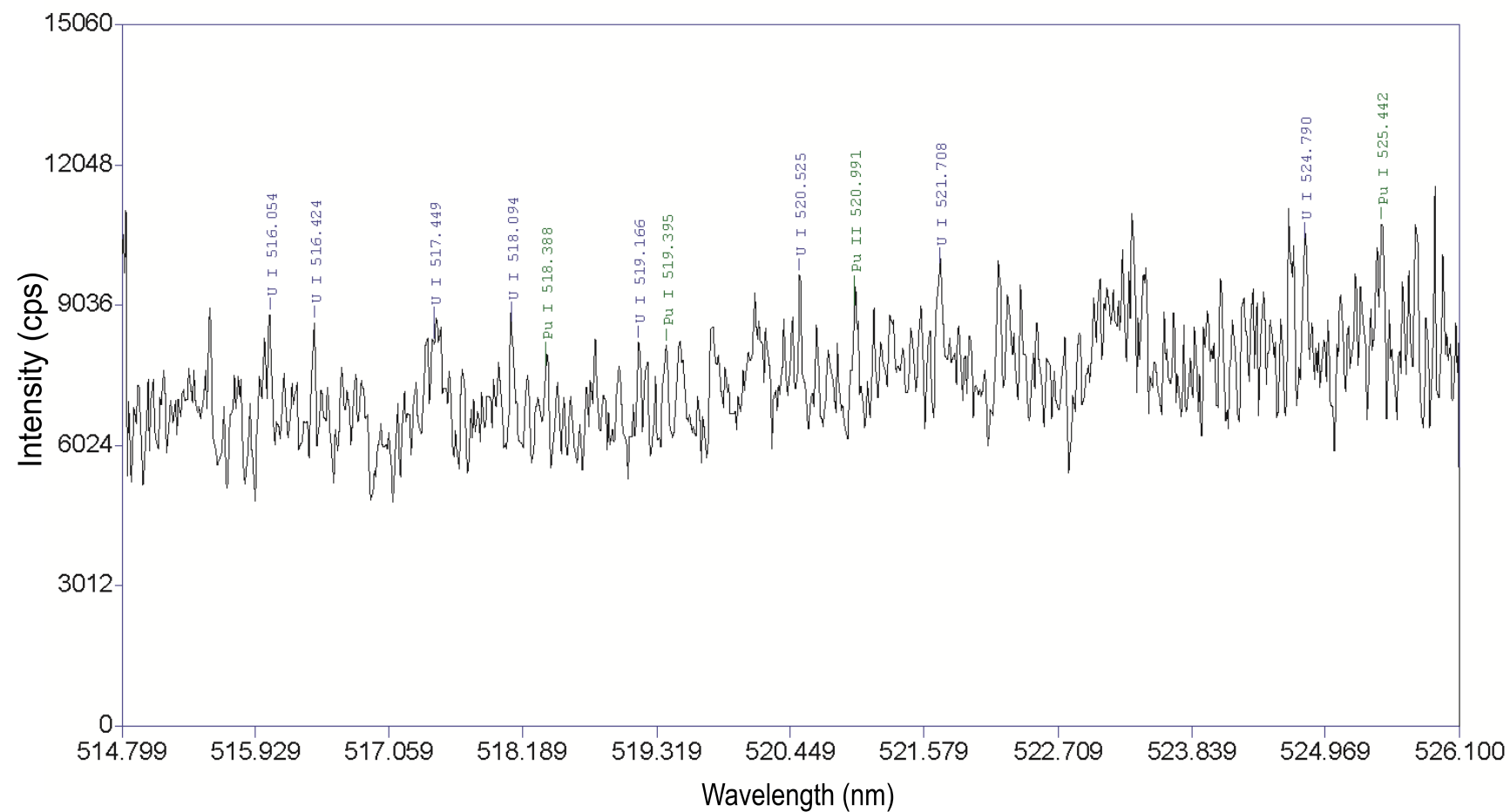


Figure 36 – Mixed Actinide Fuel Pellet (514 – 526 nm).

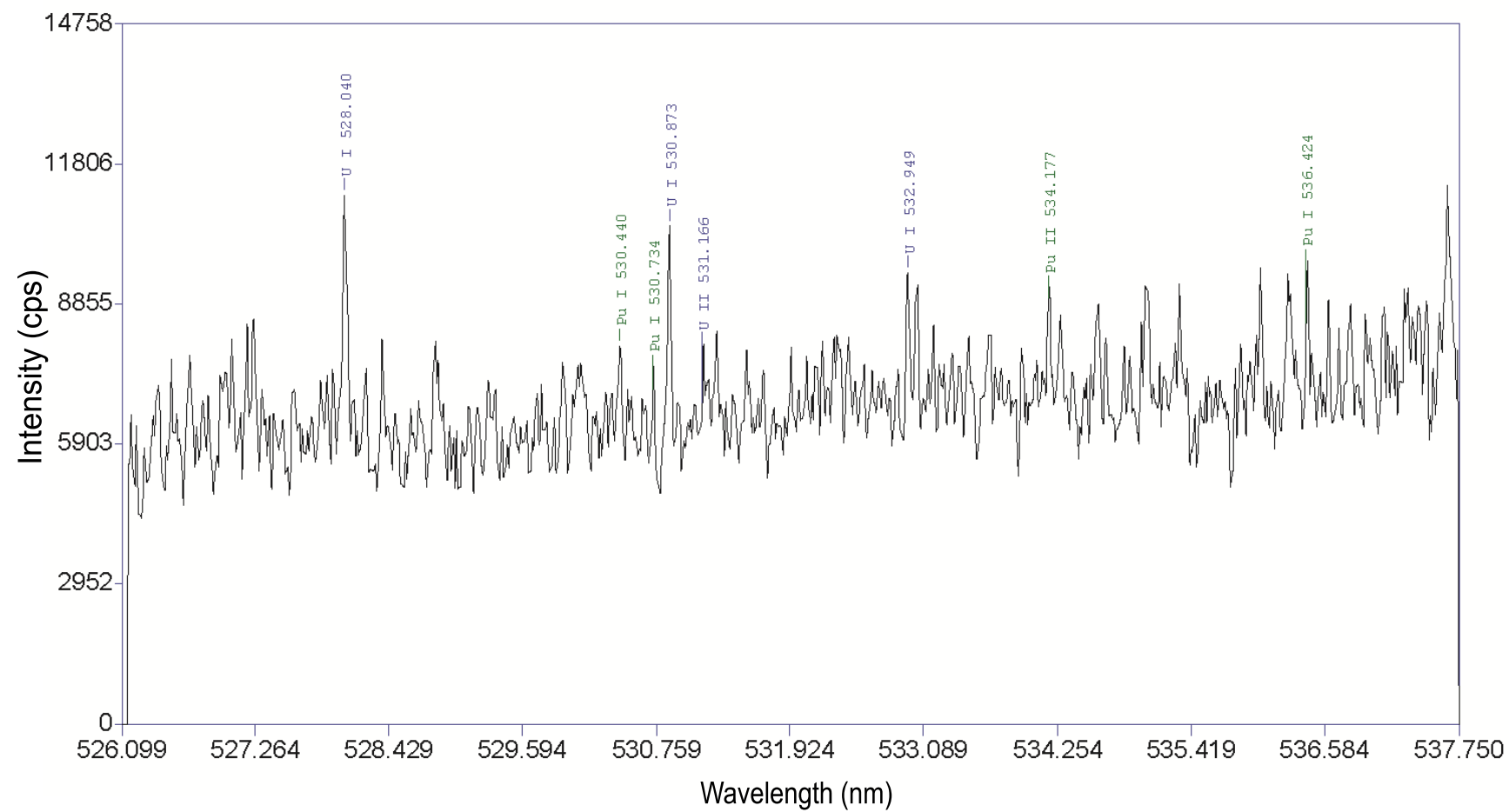


Figure 37 – Mixed Actinide Fuel Pellet (526 –537 nm).

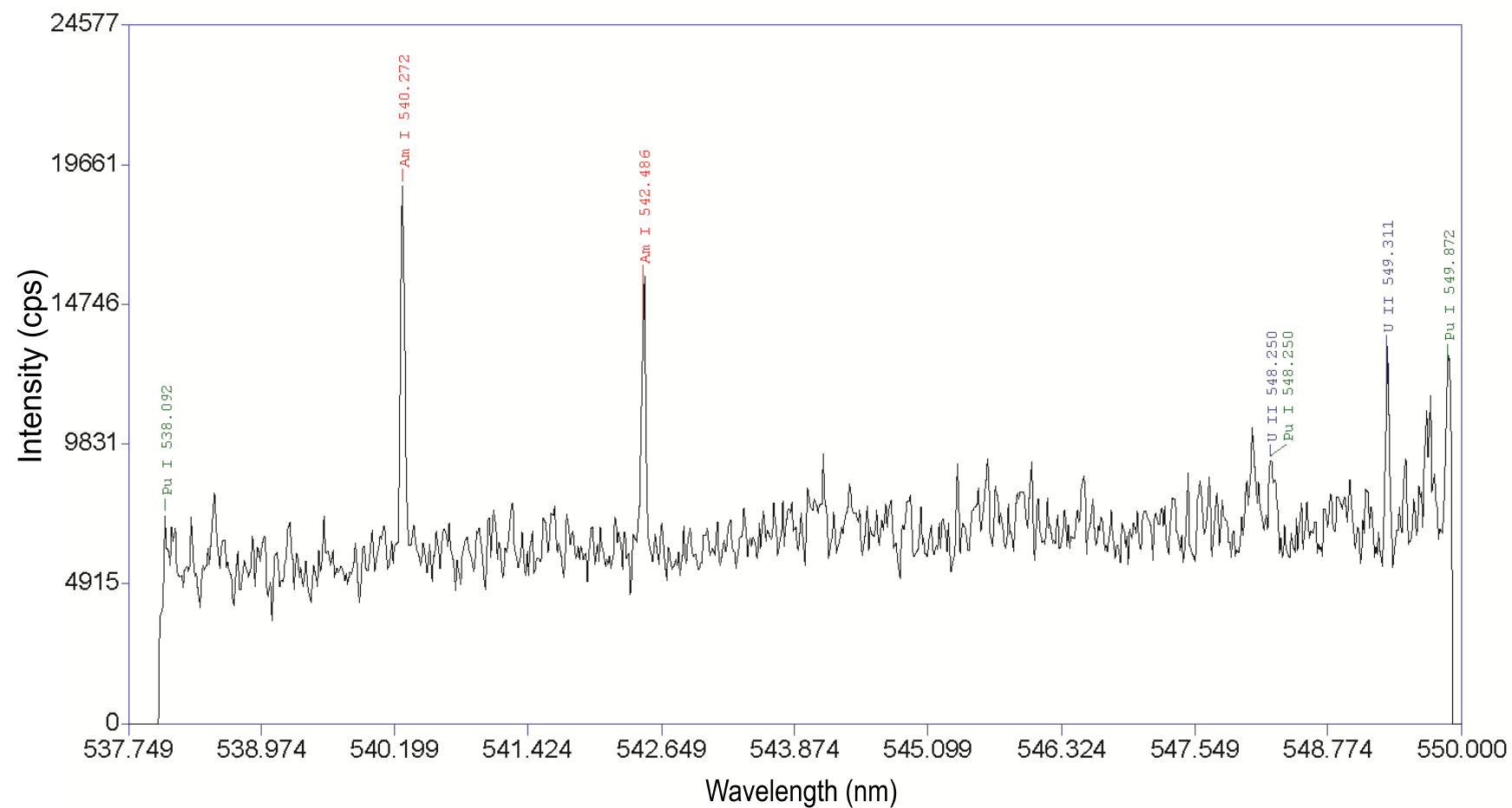


Figure 38 – Mixed Actinide Fuel Pellet (537 –550 nm).

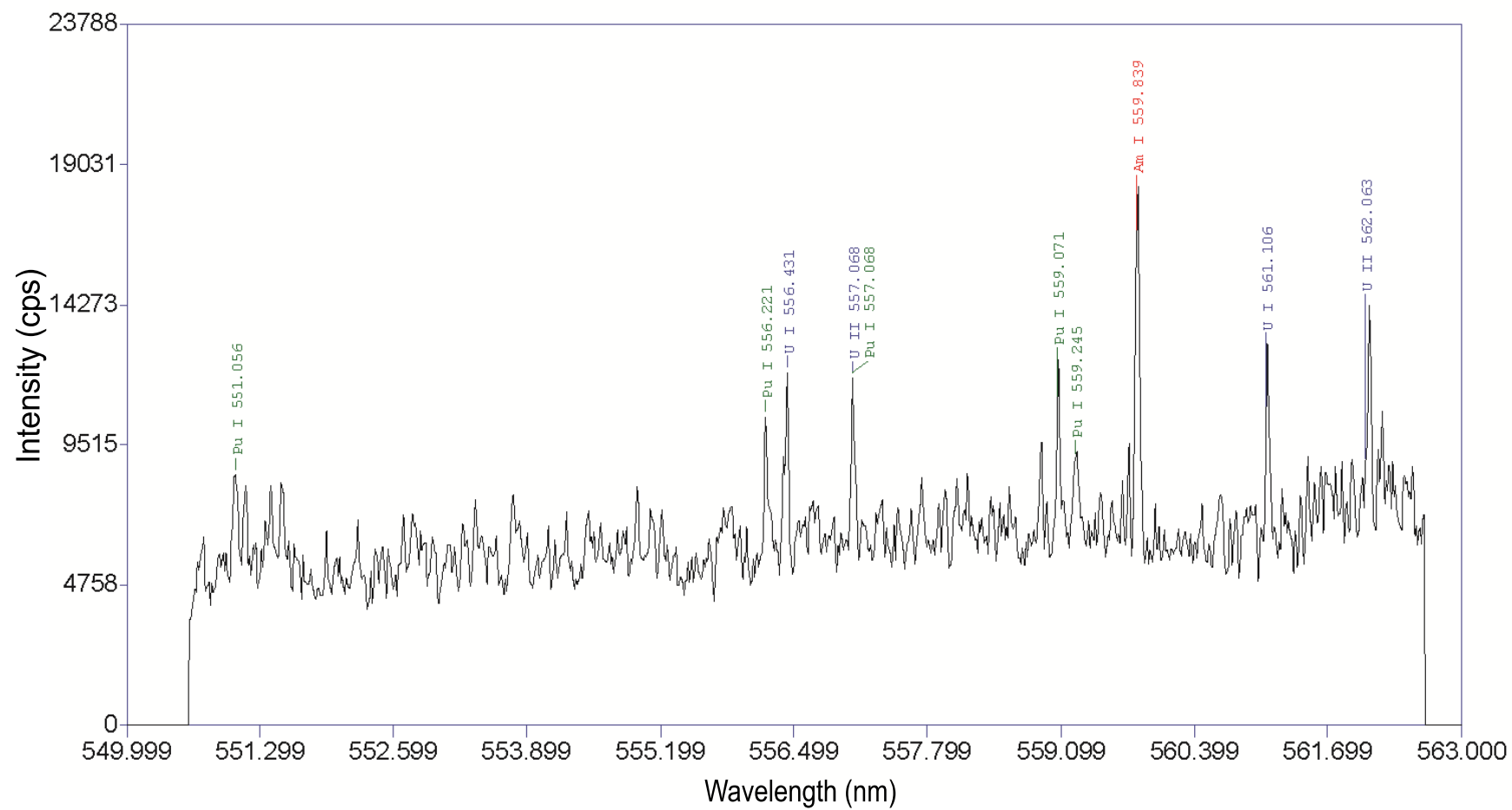


Figure 39 – Mixed Actinide Fuel Pellet (550 – 563 nm).

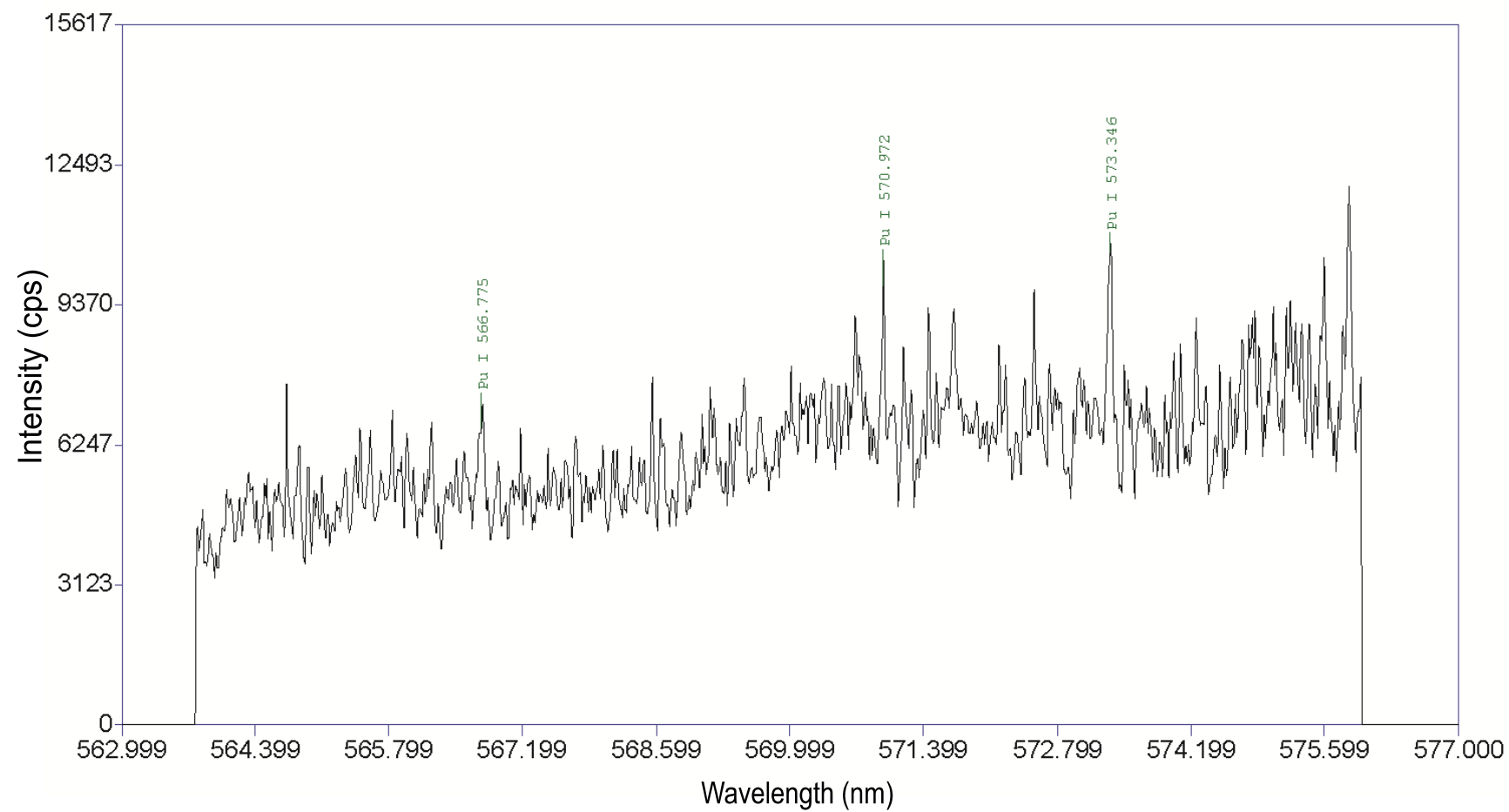


Figure 40 – Mixed Actinide Fuel Pellet (563 – 577 nm).

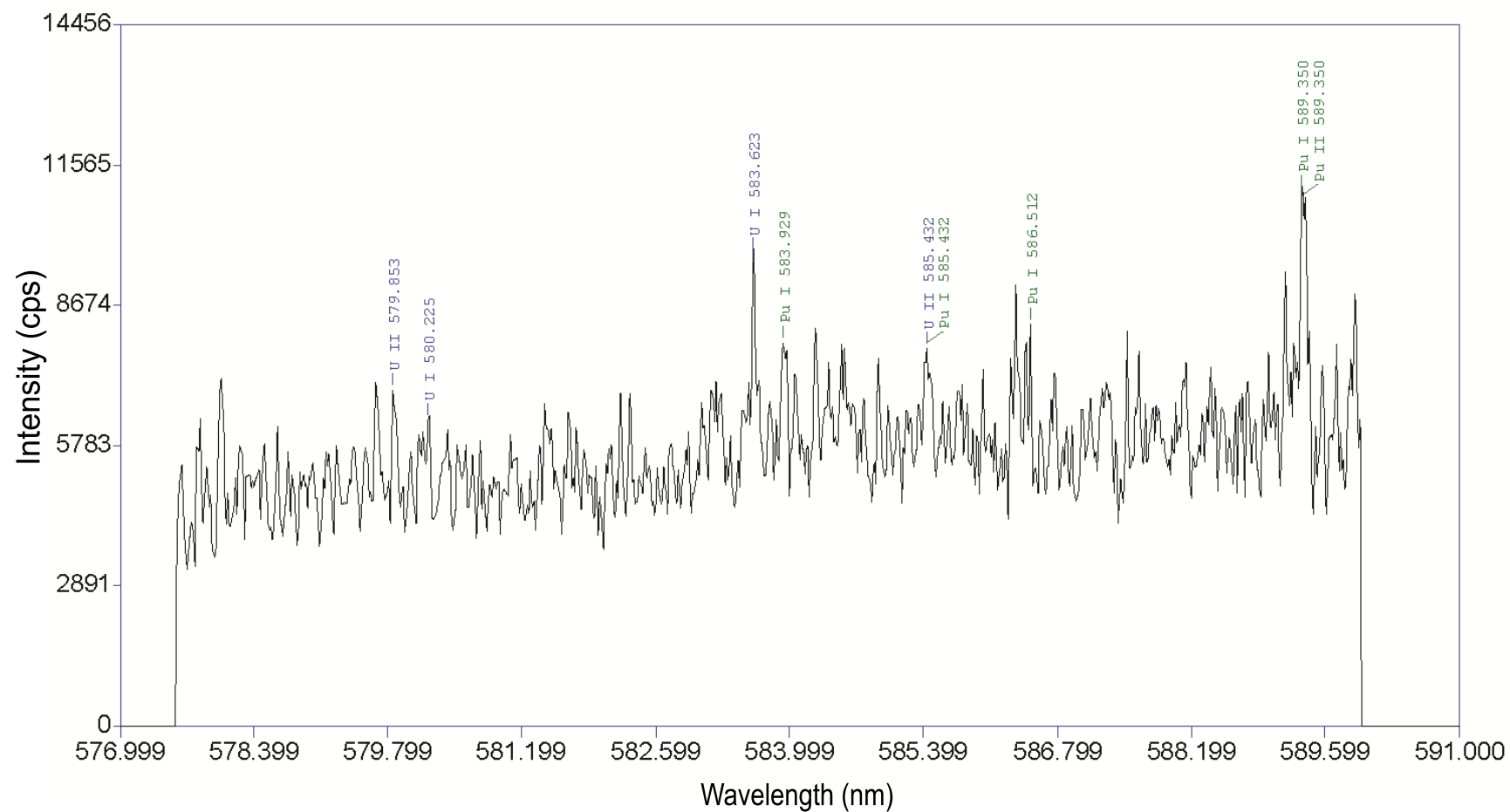


Figure 41 – Mixed Actinide Fuel Pellet (577 – 591 nm).

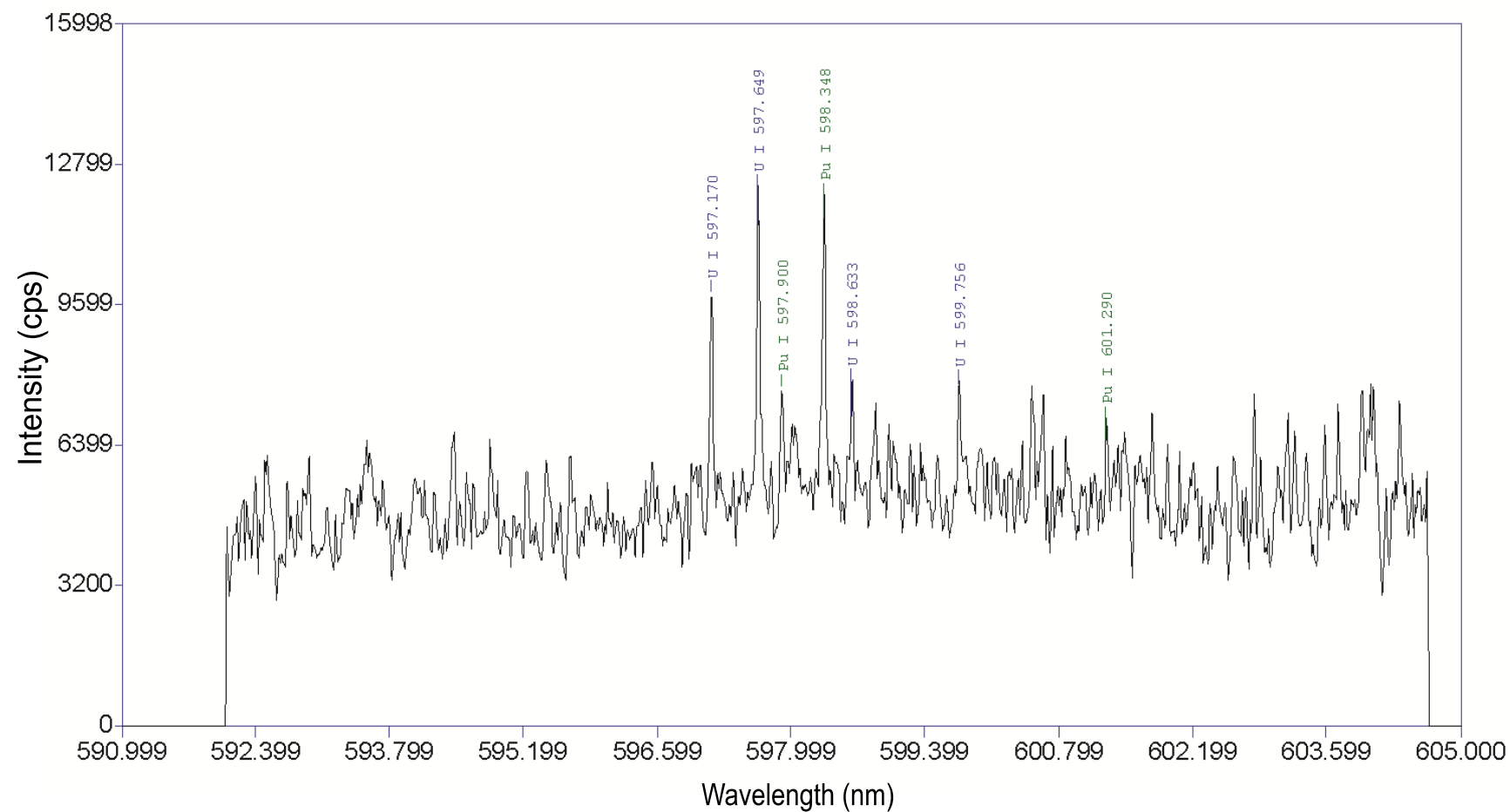


Figure 42 – Mixed Actinide Fuel Pellet (591 – 605 nm).

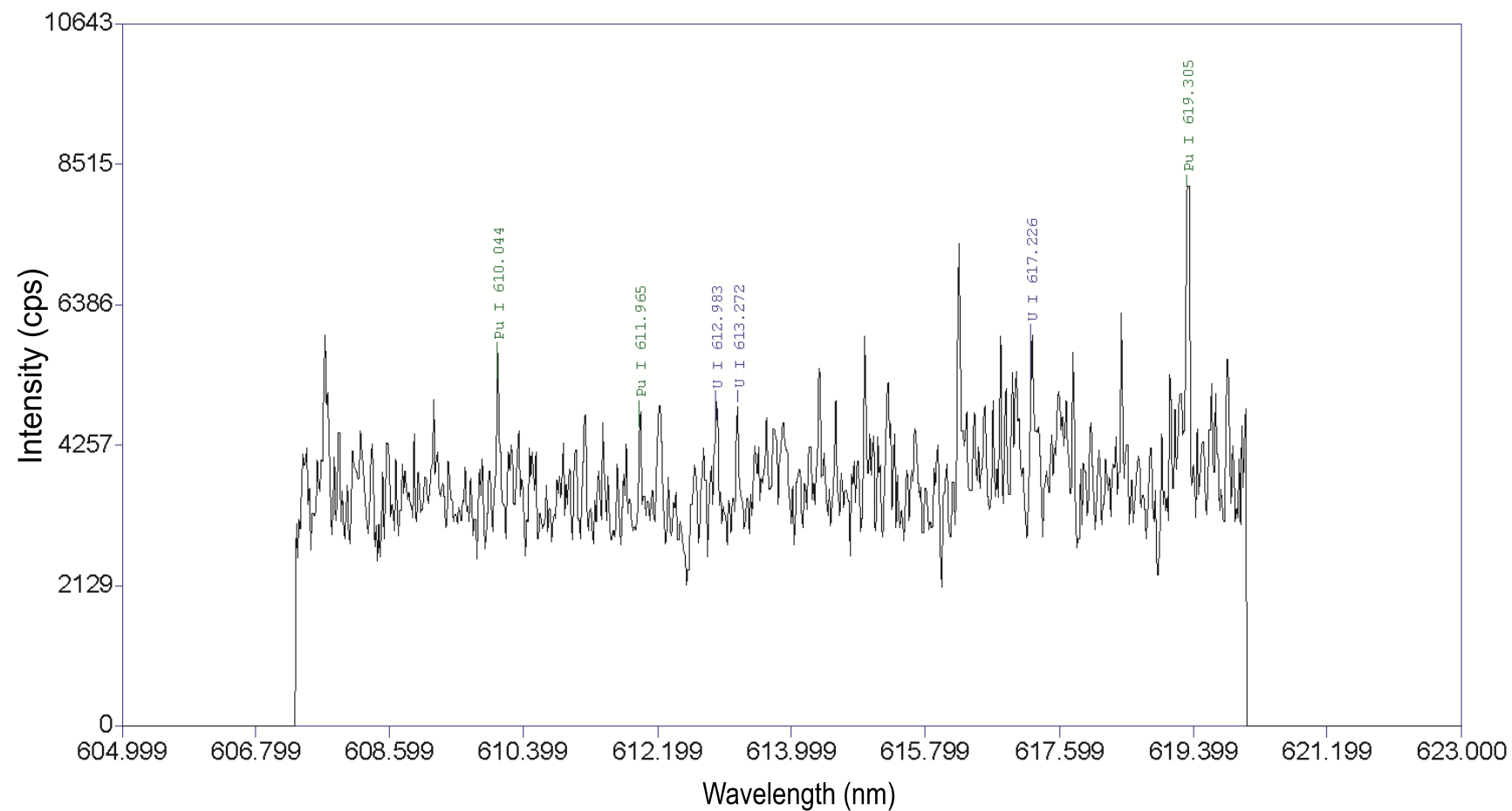


Figure 43 – Mixed Actinide Fuel Pellet (605 – 623 nm).

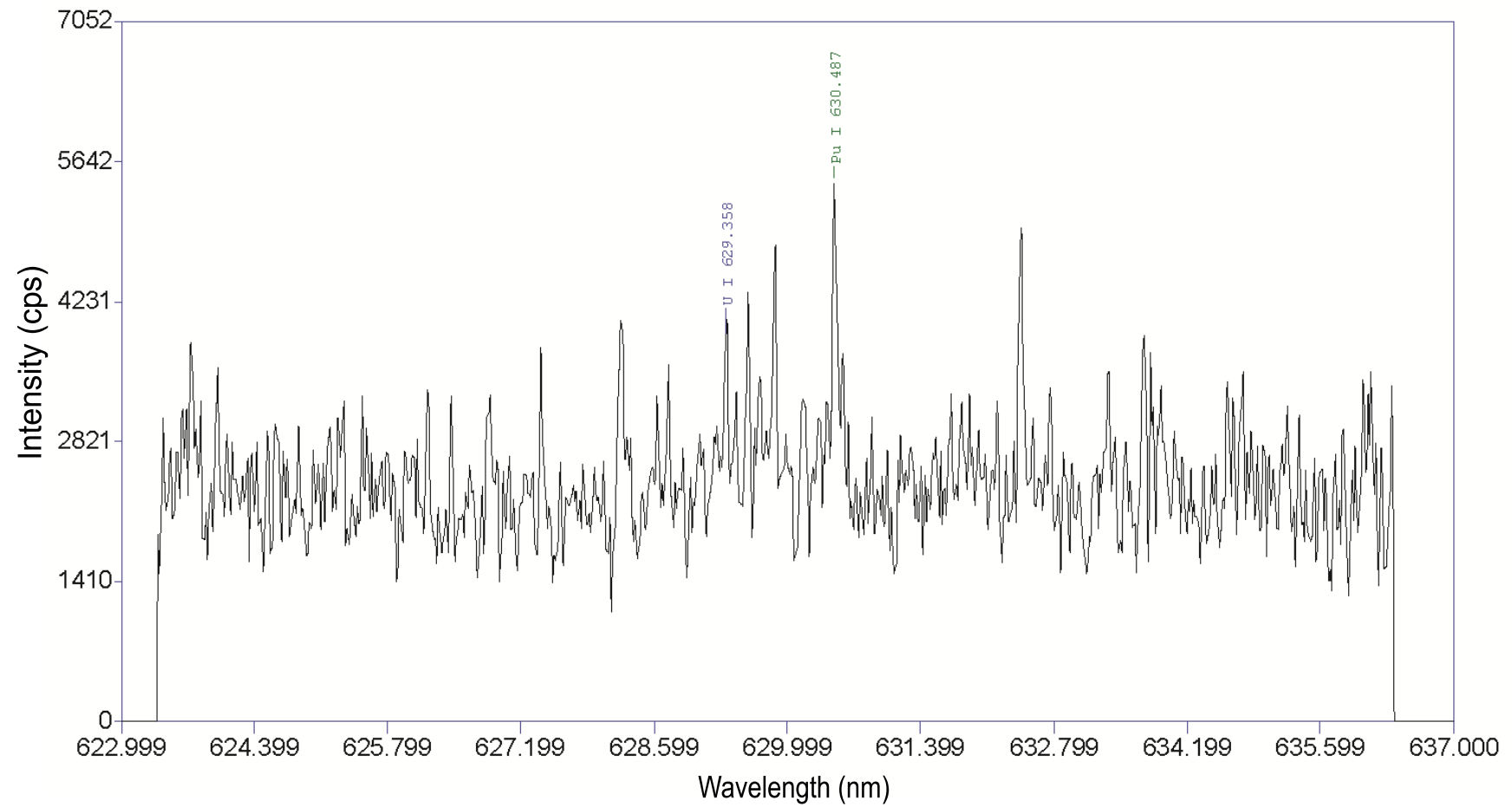


Figure 44 – Mixed Actinide Fuel Pellet (623 – 637 nm).

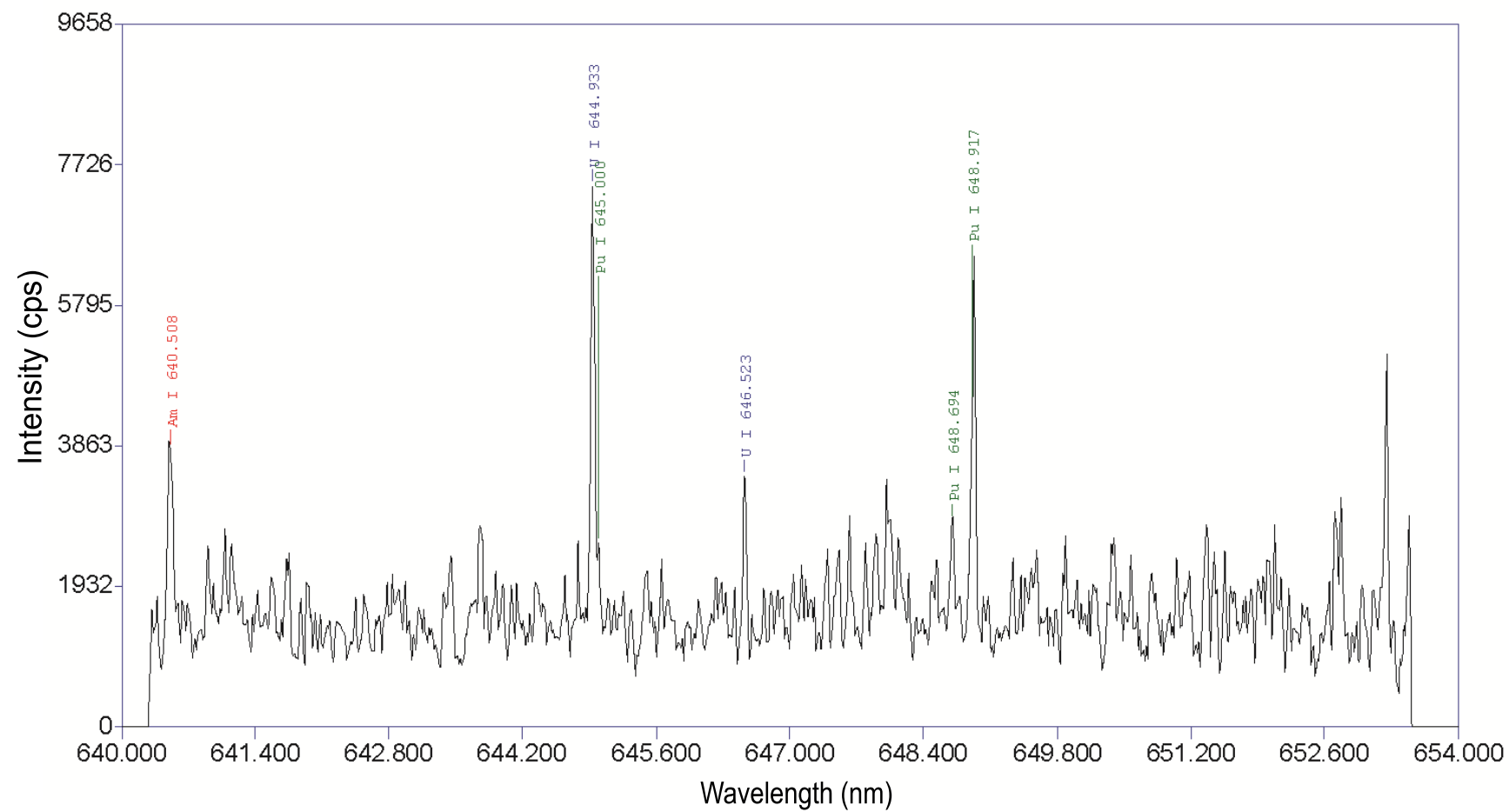


Figure 45 – Mixed Actinide Fuel Pellet (640 – 654 nm).

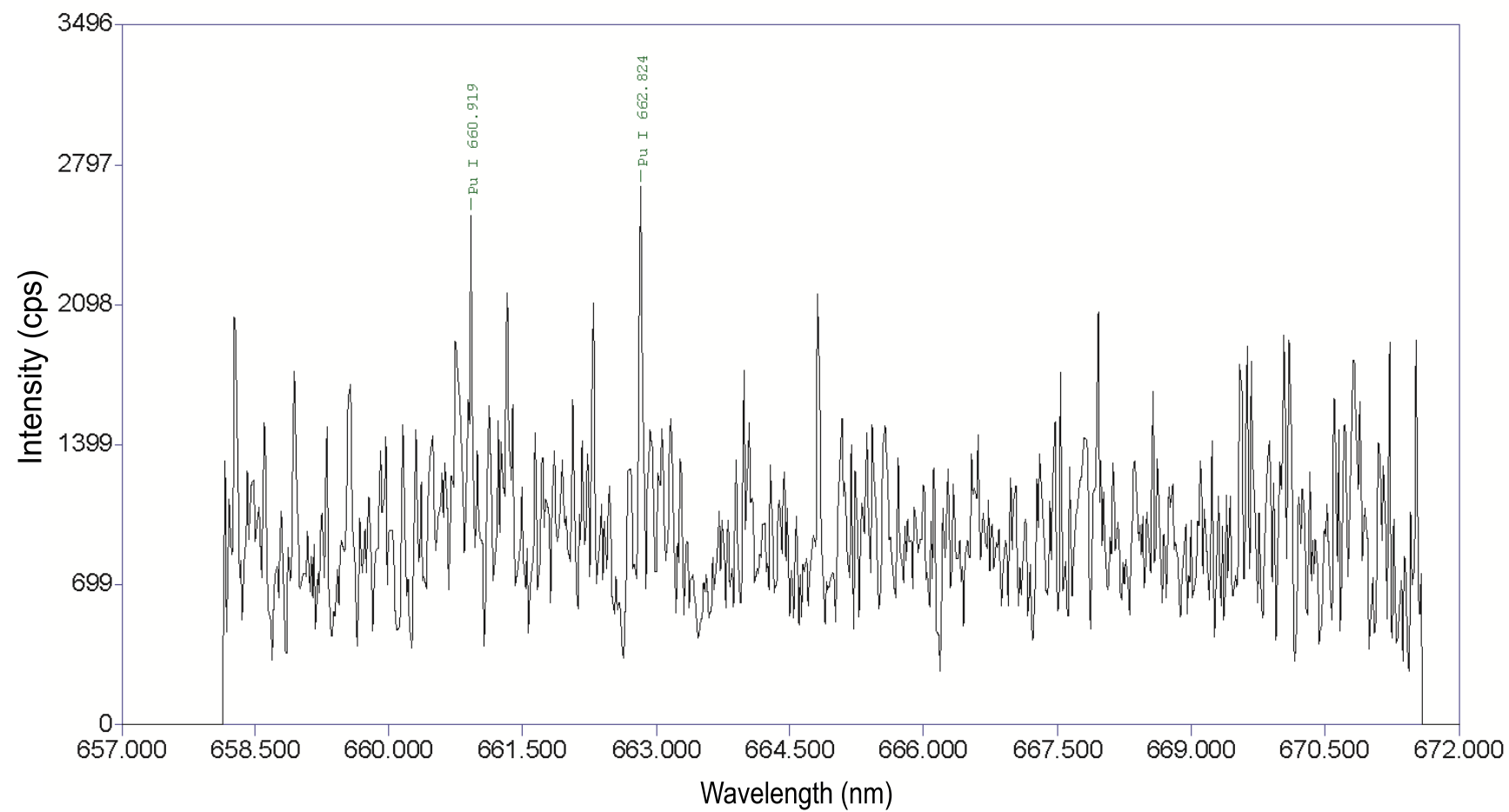


Figure 46 – Mixed Actinide Fuel Pellet (657 – 672 nm).

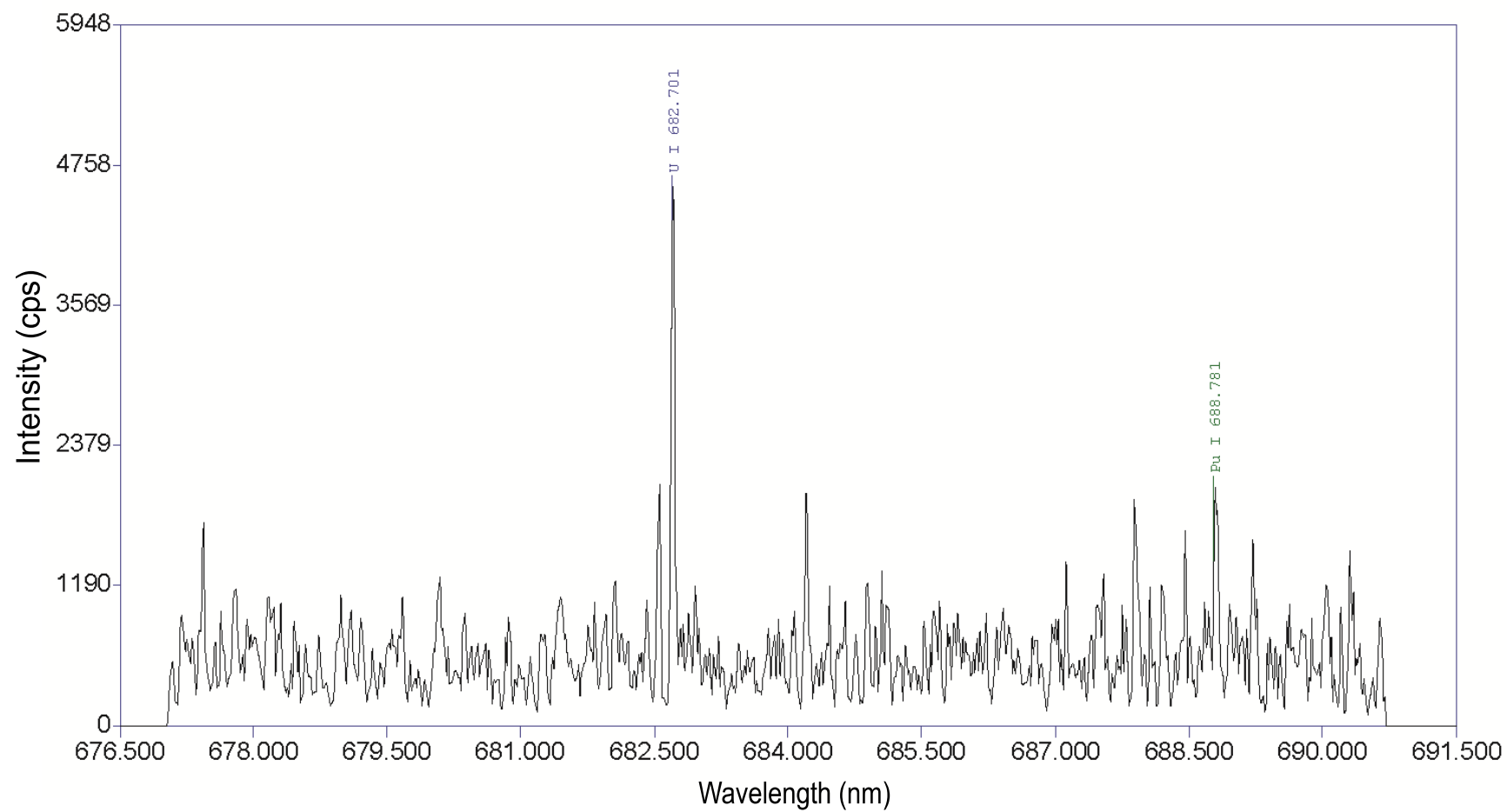


Figure 47 – Mixed Actinide Fuel Pellet (676 – 691 nm).

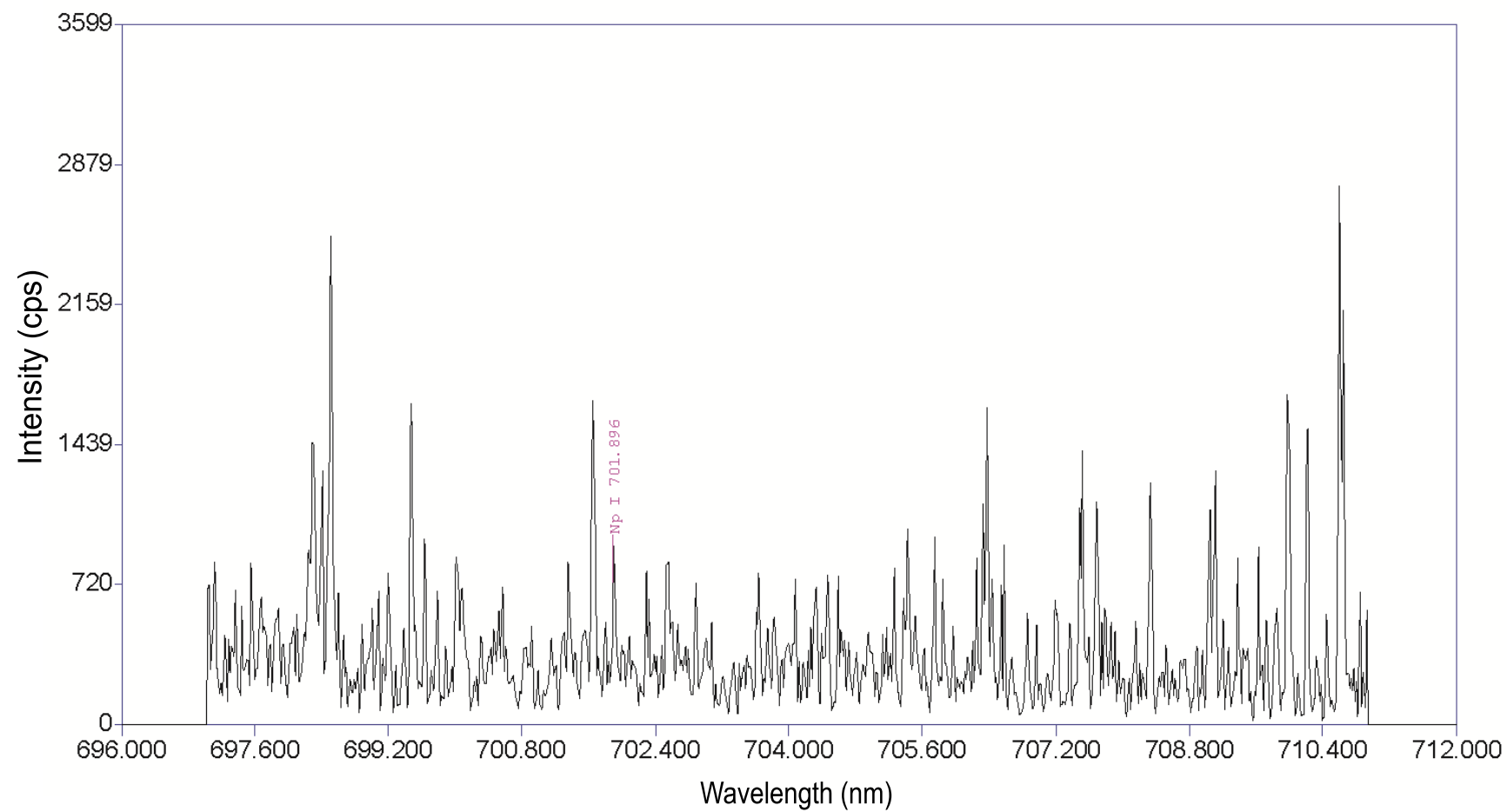


Figure 48 – Mixed Actinide Fuel Pellet (696 – 712 nm).

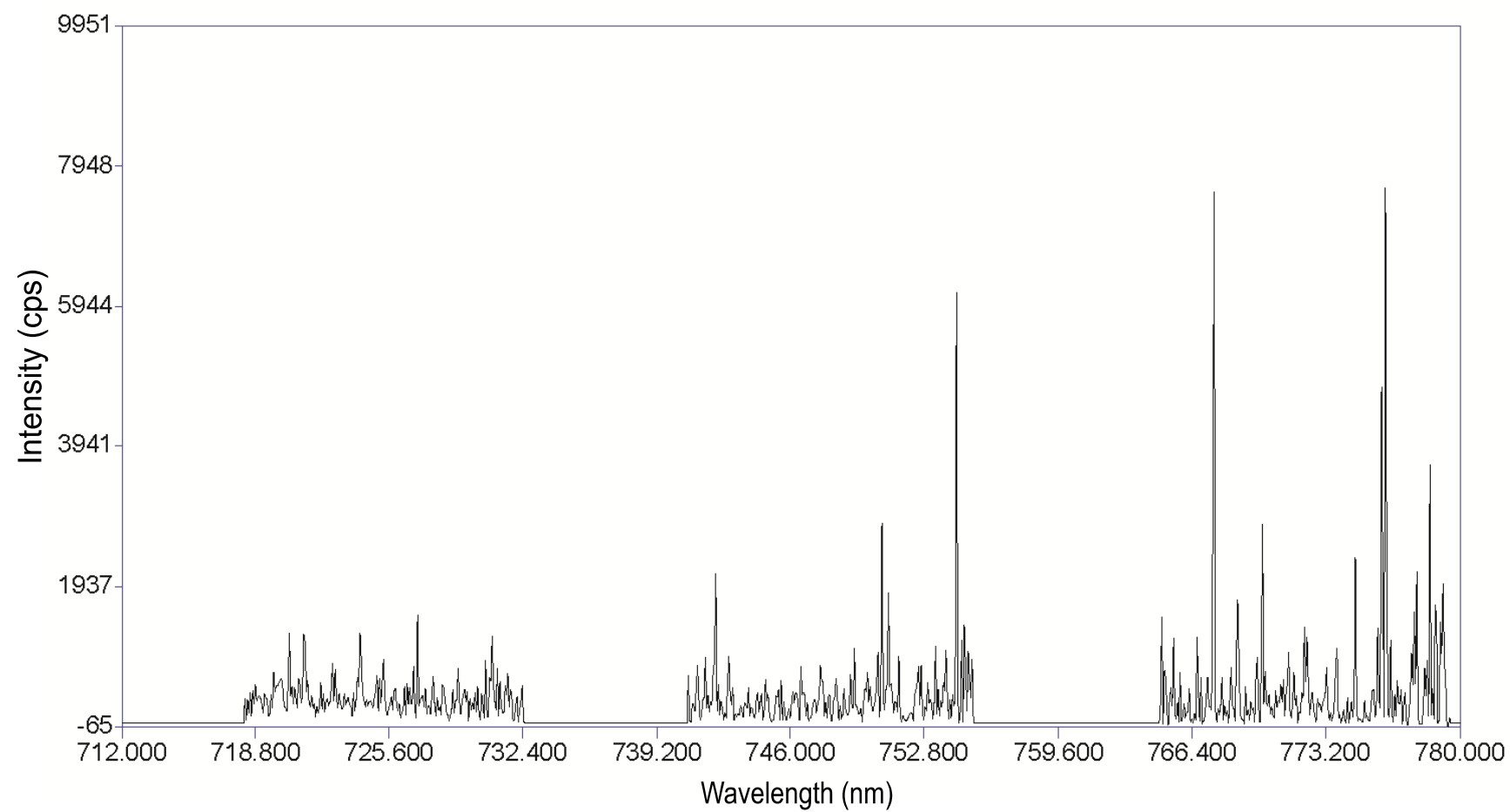


Figure 49 – Mixed Actinide Fuel Pellet (712 – 780 nm).

Table 2. Observed and literature-based wavelengths for the LIBS spectral data of a mixed actinide fuel pellet containing 75% UO_2 / 20% PuO_2 / 3% AmO_2 / 2% NpO_2 . References for the atomic emission lines are listed below. Ionic state (I) and (II) refer to the neutral and first ionic state of the element.

NIST: NIST Atomic Spectra Database

KPNO: B.A. Palmer et al. "An Atlas of Uranium Emission Intensities in a Hollow Cathode Discharge" taken at the Kitt Peak National Observatory

SAO: R.L. Kurucz 1995 Atomic Line Data from the Smithsonian Astrophysical Observatory

BFG: J. Blaise et al. "The Atomic Spectrum of Plutonium" from Argonne National Laboratory

FT: M. Fred and F.S. Tomkins, "Preliminary Term Analysis of Am I and Am II Spectra," Journal of the Optical Society of America, 47, 1076, (1957)

Notes refer to spectral characteristics of the preliminary data:

a: May contain uranium

b: May contain plutonium

c: May contain neptunium

d: May contain americium

e: Shoulder peak

f: 2 lines for emission

g: 3 lines for emission

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
343.403	343.3902	U	I	SAO	
343.432	343.4143	U	II	SAO	
343.562	343.549	U	I	NIST	
343.985	343.9780	Am	II	FT	
344.250	344.25540	Pu	II	BFG	
344.299	344.2949	U	I	SAO	
344.397	344.40575	Pu	II	BFG	
344.414	344.40865	Pu	I	BFG	
344.629	344.6186	Am	I	FT	
344.919	344.90673	Pu	II	BFG	
345.202	345.2098	Am	II	FT	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
345.302	345.29130	Pu	I	BFG	
345.361	345.34490	Pu	I	BFG	
345.361	345.355	U	II	NIST	
345.389	345.423	U	II	NIST	
345.565	345.5744	U	II	SAO	
345.611	345.60834	Pu	I	BFG	
345.719	345.705	U	II	NIST	
345.782	345.771	U	II	NIST	
345.827	345.8170	U	I	SAO	
346.008	345.9919	U	I	SAO	
346.062	346.07362	Pu	II	BFG	
346.235	346.222	U	I	NIST	
346.518	346.51002	Pu	II	BFG	
346.636	346.630	U	I	NIST	
346.929	346.91637	Pu	II	BFG	
347.257	347.252	U	II	NIST	
347.364	347.343	U	I	NIST	
347.364	347.36448	Pu	II	BFG	
347.657	347.64948	Pu	I	BFG	
347.791	347.79104	Pu	I	BFG	
347.858	347.85977	Pu	I	BFG	
348.047	348.036	U	I	NIST	
348.196	348.193	Np	I	NIST	
348.255	348.249	U	II	NIST	
348.337	348.32030	Pu	II	BFG	
348.337	348.3308	Am	II	FT	
348.947	348.9367	U	I	SAO	
349.338	349.333	U	II	NIST	
349.407	349.3996	U	I	SAO	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
349.485	349.484	U	II	NIST	
349.650	349.64059	Pu	I	BFG	
349.650	349.641	U	II	NIST	
349.735	349.72321	Pu	II	BFG	a
349.868	349.86427	Pu	I	BFG	
349.964	349.95911	Pu	I	BFG	
350.016	350.0076	U	I	SAO	
350.144	350.150	Np	I	NIST	
350.412	350.401	U	I	NIST	
350.718	350.7053	U	I	SAO	
350.746	350.734	U	I	NIST	
350.893	350.884	U	II	NIST	
351.023	351.0127	Am	I	FT	
351.157	351.1443	U	I	SAO	
351.175	351.17826	Pu	I	BFG	
351.193	351.19564	Pu	II	BFG	
351.379	351.367	U	I	NIST	
351.472	351.44247	Pu	I	BFG	
351.472	351.461	U	I	NIST	
352.005	351.9955	U	II	SAO	
352.279	352.2672	U	I	SAO	
352.578	352.5652	U	I	SAO	
352.683	352.6596	U	II	SAO	
353.107	353.0948	Am	I	FT	
353.107	353.111	U	II	NIST	
353.170	353.1645	U	I	SAO	
353.305	353.30633	Pu	II	BFG	
353.373	353.357	U	II	NIST	
353.448	353.433	U	I	NIST	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
353.669	353.65253	Pu	I	BFG	
353.746	353.7288	U	I	NIST	
353.845	353.8235	U	I	SAO	
353.924	353.91815	Pu	II	BFG	
353.978	353.9651	U	I	SAO	
354.007	353.99959	Pu	II	BFG	
354.057	354.047	U	II	NIST	
354.088	354.07046	Pu	II	BFG	
354.088	354.08501	Pu	I	BFG	
354.263	354.257	U	I	NIST	
354.663	354.6677	U	II	SAO	
354.931	354.94145	Pu	I	BFG	
355.097	355.082	U	II	NIST	
355.541	355.532	U	I	NIST	
355.798	355.7841	U	I	NIST	
356.152	356.141	U	I	NIST	
356.192	356.180	U	I	NIST	
356.375	356.3656	U	I	SAO	
356.671	356.659	U	I	NIST	
356.780	356.78388	Pu	II	BFG	
356.926	356.908	U	I	NIST	
356.926	356.9163	Am	I	FT	
357.377	357.411	U	I	NIST	
357.491	357.476	U	I	NIST	
357.806	357.792	U	I	NIST	b
358.034	358.0246	U	I	NIST	
358.272	358.2622	U	I	NIST	
358.502	358.488	U	I	NIST	
358.598	358.5837	U	I	NIST	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
358.598	358.58665	Pu	II	BFG	a
358.985	358.9787	U	I	NIST	
359.057	359.050	U	II	NIST	
359.186	359.174	U	I	NIST	
359.321	359.3194	U	I	NIST	
359.378	359.37209	Pu	I	BFG	
359.428	359.42914	Pu	I	BFG	
359.489	359.4955	U	II	SAO	
359.578	359.57176	Pu	II	BFG	
360.258	360.2483	U	I	SAO	
360.258	360.26801	Pu	II	BFG	
360.352	360.3410	Am	I	FT	a
360.384	360.39955	Pu	II	BFG	e
360.546	360.527	U	I	NIST	
360.640	360.632	U	II	NIST	
360.980	360.97622	Pu	II	BFG	
361.642	361.633	U	I	NIST	
361.684	361.676	U	II	NIST	
361.757	361.7490	U	I	SAO	
362.020	362.008	U	I	NIST	
362.286	362.270	U	I	NIST	
362.315	362.306	U	II	NIST	
362.708	362.69901	Pu	I	BFG	
362.761	362.75238	Pu	II	BFG	
363.087	363.073	U	II	NIST	
363.232	363.22100	Pu	I/II	BFG	f
363.543	363.5410	U	II	SAO	
363.647	363.64311	Pu	II	BFG	
363.769	363.7510	U	I	SAO	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
363.830	363.820	U	I	NIST	
363.876	363.87573	Pu	I	BFG	a
363.959	363.97867	Pu	II	BFG	a
364.124	364.0945	U	II	SAO	
364.251	364.2428	U	I	SAO	
364.435	364.424	U	I	NIST	
364.696	364.67251	Pu	I	BFG	a
364.815	364.81211	Pu	I	BFG	a
365.157	365.14134	Pu	II	BFG	a
365.211	365.206	U	I	NIST	b
365.497	365.4900	U	I	SAO	
365.925	365.915	U	I	NIST	b
365.966	365.94538	Pu	II	BFG	a
366.733	366.72421	Pu	I	BFG	
367.021	367.007	U	II	NIST	
367.070	367.0528	U	I	SAO	
367.324	367.3121	Am	I	FT	
367.663	367.6562	U	II	SAO	
367.759	367.7389	U	I	SAO	
367.759	367.75618	Pu	I	BFG	
367.950	367.9371	U	I	SAO	b
367.950	367.96500	Pu	II	BFG	
368.097	368.0878	U	I	SAO	
368.251	368.2457	U	I	SAO	
368.393	368.37996	Pu	I	BFG	
368.470	368.4570	Am	II	FT	a
368.593	368.5774	U	I	SAO	
369.038	369.03501	Pu	II	BFG	
369.217	369.192	U	II	NIST	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
369.536	369.51960	Pu	I	BFG	
369.536	369.53084	Pu	II	BFG	
369.652	369.6420	Am	II	FT	
369.857	369.85167	Pu	II	BFG	
369.936	369.91852	Pu	II	BFG	
369.936	369.91993	Pu	I	BFG	
369.936	369.94357	Pu	II	BFG	
370.122	370.10794	Pu	II	BFG	
370.157	370.1516	U	II	SAO	
370.274	370.2613	U	I	SAO	
370.335	370.3271	U	I	SAO	
370.415	370.4085	U	I	SAO	
370.599	370.59629	Pu	I	BFG	
370.651	370.64189	Pu	I	BFG	
370.748	370.7285	U	I	SAO	
370.799	370.7856	Am	I	FT	
370.920	370.91270	Pu	II	BFG	
371.378	371.3648	U	II	SAO	e
371.396	371.38912	Pu	I	BFG	
371.487	371.47236	Pu	I	BFG	
371.487	371.4757	U	II	SAO	
371.629	371.6135	U	I	SAO	
371.822	371.811	U	II	NIST	
371.822	371.81202	Pu	II	BFG	
371.902	371.89935	Pu	I	BFG	
371.943	371.9289	U	I	SAO	
372.022	372.02434	Pu	I/II	BFG	g,e
372.043	372.0396	U	I	SAO	e
372.063	372.05872	Pu	I	BFG	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
372.144	372.13366	Pu	I	BFG	
372.183	372.15732	Pu	II	BFG	
372.183	372.17387	Pu	I	BFG	
372.288	372.2675	U	I	SAO	
372.433	372.41546	Pu	I	BFG	
372.612	372.59819	Pu	I	BFG	
372.612	372.61097	Pu	II	BFG	
372.692	372.67963	Pu	II	BFG	
372.892	372.88354	Pu	I	BFG	
373.158	373.1444	U	I	SAO	
373.227	373.20371	Pu	II	BFG	
373.227	373.21841	Pu	I	BFG	
373.227	373.2254	U	I	SAO	
373.276	373.262	U	II	NIST	
373.326	373.307	U	II	NIST	
373.384	373.3591	U	I	SAO	
373.610	373.59628	Pu	I	BFG	a
373.815	373.804	U	II	NIST	
374.083	374.07111	Pu	I	BFG	a
374.246	374.2349	U	I	SAO	
374.435	374.425	U	II	NIST	
374.489	374.47903	Pu	I	BFG	
374.595	374.58003	Pu	I	BFG	
374.652	374.642	U	II	NIST	
374.734	374.714	U	II	NIST	
374.864	374.868	U	II	NIST	e
374.887	374.88043	Pu	I	BFG	
375.130	375.117	U	I	NIST	
375.183	375.1708	U	I	SAO	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
375.375	375.36283	Pu	I	BFG	
375.421	375.41129	Pu	I	BFG	
375.421	375.4308	U	II	SAO	
375.519	375.51045	Pu	I	BFG	a
375.519	375.52756	Pu	II	BFG	
375.605	375.59403	Pu	I	BFG	
375.794	375.78159	Pu	I	BFG	
375.844	375.83376	Pu	I	BFG	
375.901	375.89025	Pu	-	BFG	
376.078	376.0887	U	II	SAO	
376.218	376.2116	U	II	SAO	
376.339	376.326	U	I	NIST	
376.394	376.38841	Pu	I	BFG	a
376.468	376.457	U	II	NIST	
376.545	376.5348	U	I	SAO	
376.607	376.59299	Pu	I	BFG	
376.700	376.689	U	I	NIST	
376.760	376.74227	Pu	II	BFG	
376.760	376.74781	Pu	I	BFG	
376.828	376.82086	Pu	I	BFG	
376.874	376.8795	U	II	SAO	
377.356	377.343	U	I	NIST	
377.356	377.35934	Pu	II	BFG	
377.448	377.43843	Pu	I	BFG	
377.566	377.56483	Pu	II	BFG	
377.678	377.67121	Pu	I	BFG	
377.678	377.68021	Pu	I	BFG	
377.750	377.7504	Am	II	FT	
377.981	377.97373	Pu	I	BFG	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
378.077	378.0714	U	II	SAO	
378.295	378.284	U	II	NIST	
378.382	378.384	U	II	NIST	
378.695	378.6826	U	I	SAO	
378.738	378.7235	U	II	SAO	
378.738	378.72664	Pu	I	BFG	
378.824	378.8161	U	I	SAO	
379.049	379.0209	U	II	SAO	
379.234	379.22196	Pu	I	BFG	
379.234	379.2412	U	I	SAO	
379.337	379.310	U	II	NIST	
379.367	379.357	U	II	NIST	
379.527	379.5113	U	II	SAO	
379.785	379.7767	U	I	SAO	
379.943	379.9197	U	II	SAO	e
379.943	379.93679	Pu	I	BFG	
380.120	380.10462	Pu	I	BFG	
380.120	380.1145	U	I	SAO	
380.219	380.21245	Pu	I	BFG	
380.219	380.2278	U	II	SAO	
380.605	380.59228	Pu	I	BFG	
380.856	380.84250	Pu	I	BFG	
380.921	380.892	U	I	NIST	
380.921	380.91326	Pu	I	BFG	
380.921	380.922	U	II	NIST	
380.966	380.95376	Pu	I	BFG	
381.027	381.0095	U	I	SAO	
381.027	381.01876	Pu	II	BFG	
381.154	381.13965	Pu	I	BFG	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
381.212	381.199	U	I	NIST	
381.212	381.23007	Pu	II	BFG	
381.374	381.35854	Pu	I	BFG	
381.374	381.379	U	II	NIST	
381.517	381.48833	Pu	II	BFG	
381.517	381.50431	Pu	I	BFG	
381.644	381.63339	Pu	I	BFG	
381.820	381.8058	U	I	SAO	
381.860	381.84871	Pu	I	BFG	
381.949	381.93686	Pu	I	BFG	
382.120	382.11111	Pu	I	BFG	
382.203	382.1947	U	I	SAO	
382.666	382.651	U	II	NIST	
382.766	382.75719	Pu	I	BFG	
382.913	382.9020	U	II	SAO	
382.913	382.90577	Pu	I	BFG	
382.979	382.96171	Pu	I	BFG	a
383.156	383.146	U	II	NIST	
383.515	383.50234	Pu	I	BFG	
383.515	383.5224	U	I	SAO	
383.556	383.55205	Pu	I	BFG	
383.593	383.58882	Pu	I	BFG	
383.593	383.5914	U	II	SAO	
383.703	383.69572	Pu	I	BFG	
383.900	383.89146	Pu	I	BFG	
383.974	383.963	U	I	NIST	
384.219	384.20929	Pu	I	BFG	
384.411	384.39845	Pu	I	BFG	
384.411	384.41047	Pu	I	BFG	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
384.665	384.6553	U	I	SAO	
384.728	384.71119	Pu	I	BFG	
385.111	385.10067	Pu	I	BFG	
385.111	385.11780	Pu	II	BFG	
385.192	385.17103	Pu	I	BFG	
385.192	385.18493	Pu	I	BFG	
385.431	385.4220	U	I	SAO	
385.472	385.464	U	II	NIST	
385.553	385.54282	U	I	KPNO	
385.619	385.61037	Pu	I	BFG	
385.920	385.90082	U	II	KPNO	
385.967	385.957	U	II	NIST	
386.126	386.117	U	II	NIST	
386.247	386.23251	Pu	I	BFG	
386.286	386.30935	U	I	KPNO	
386.458	386.44576	Pu	I	BFG	
386.458	386.4467	U	II	SAO	
386.508	386.50653	Pu	II	BFG	a
386.605	386.592	U	II	NIST	
386.706	386.680	U	II	NIST	
386.731	386.71716	U	I	KPNO	
386.765	386.75047	U	I	KPNO	
386.881	386.86969	U	I	KPNO	
386.983	386.97043	Pu	I	BFG	a
387.022	387.01050	Pu	I	BFG	a
387.121	387.10353	U	I	KPNO	
387.418	387.40387	U	II	KPNO	
387.418	387.41965	Pu	II	BFG	
387.449	387.44580	U	I	KPNO	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
387.626	387.6133	U	I	SAO	
387.863	387.85403	Pu	I	BFG	
387.863	387.85738	U	I	KPNO	
387.969	387.9711	U	I	SAO	
388.154	388.14546	U	II	KPNO	
388.248	388.23556	U	II	KPNO	
388.873	388.85951	Pu	I	BFG	a
388.935	388.94039	Pu	I	BFG	a
389.044	389.03615	U	-	KPNO	
389.185	389.18015	U	I	KPNO	
389.253	389.26810	U	II	KPNO	
389.425	389.41206	U	I	KPNO	
389.596	389.58876	Pu	I	BFG	
390.269	390.25507	U	II	KPNO	
390.291	390.28125	Pu	I	BFG	e
390.444	390.41203	Pu	II	BFG	
390.444	390.42940	U	-	KPNO	
390.465	390.4563	U	II	SAO	e
390.724	390.72145	Pu	II	BFG	
390.837	390.8308	U	I	SAO	
391.136	391.12216	Pu	I	BFG	
391.178	391.167	U	II	NIST	
391.260	391.25648	Pu	II	BFG	
391.353	391.34803	Pu	II	BFG	
391.530	391.52072	U	I	KPNO	
391.653	391.65205	U	I	KPNO	
391.743	391.76083	U	II	KPNO	
391.881	391.87131	Pu	I	BFG	
392.119	392.11897	U	I	KPNO	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
392.312	392.30225	U	I	KPNO	
392.637	392.62078	U	I	KPNO	
392.637	392.6248	Am	II	FT	
392.682	392.68133	U	I	KPNO	
392.869	392.85287	Pu	I	BFG	
393.057	393.04396	U	I	KPNO	
393.112	393.09777	U	II	KPNO	
393.214	393.20221	U	II	KPNO	
393.376	393.36614	Ca	II	NIST	
393.552	393.538	U	II	NIST	
393.647	393.63204	Pu	I	BFG	
393.961	393.94938	Pu	I	BFG	
394.065	394.04838	U	II	KPNO	
394.159	394.15077	Pu	I	BFG	
394.268	394.26112	U	I	KPNO	
394.301	394.28138	U	I	KPNO	
394.396	394.38161	U	I	KPNO	
394.435	394.41297	U	II	KPNO	
394.678	394.66236	U	-	KPNO	
394.756	394.75015	U	I	KPNO	
394.856	394.84430	U	I	KPNO	
395.060	395.04731	U	I	KPNO	
395.156	395.1474	U	I	SAO	
395.264	395.25466	U	II	KPNO	
395.264	395.2576	Am	II	FT	
395.304	395.29597	U	I	KPNO	
395.304	395.30318	Pu	II	BFG	
395.341	395.358	U	II	NIST	
395.471	395.467	U	II	NIST	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
395.601	395.58790	Pu	I	BFG	
395.601	395.60154	Pu	I	BFG	
395.922	395.89610	Pu	II	BFG	a
396.053	396.04412	Pu	I	BFG	
396.118	396.14122	U	I	KPNO	
396.226	396.21498	U	I	KPNO	
396.291	396.27386	Pu	II	BFG	
396.291	396.28050	U	I	KPNO	
396.502	396.51745	U	I	KPNO	
396.649	396.65494	U	II	KPNO	
396.747	396.7463	U	I	SAO	
396.856	396.84673	Ca	II	NIST	
396.856	396.85092	U	-	KPNO	
397.227	397.22030	Pu	II	BFG	
397.227	397.22127	U	I	KPNO	
397.549	397.54246	Pu	II	BFG	
397.846	397.82661	U	-	KPNO	
398.094	398.0795	U	I	SAO	
398.314	398.30334	Pu	I	BFG	
398.387	398.37686	U	I	KPNO	
398.429	398.41785	U	-	KPNO	
398.563	398.55301	Pu	II	BFG	e
398.590	398.57924	U	II	KPNO	
398.888	398.85017	Pu	II	BFG	
398.888	398.8884	U	II	SAO	
398.938	398.92887	U	I	KPNO	
398.991	398.98313	Pu	II	BFG	
398.991	399.00441	U	-	KPNO	
398.991	399.02067	Pu	I	BFG	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
399.032	399.04203	U	II	KPNO	
399.259	399.25345	U	II	KPNO	
399.403	399.38423	U	I	KPNO	
399.527	399.51819	U	-	KPNO	
399.619	399.59779	U	-	KPNO	b
399.715	399.70817	U	I	KPNO	
399.854	399.824	U	II	NIST	
399.854	399.86491	U	-	KPNO	
399.926	399.91803	U	I	KPNO	
400.133	400.13990	U	I	KPNO	
400.417	400.406	U	II	NIST	
400.534	400.5209	U	I	SAO	
400.584	400.5695	U	I	SAO	
401.074	401.08119	U	I	KPNO	
401.161	401.14496	U	II	KPNO	
401.161	401.17811	U	I	KPNO	
401.298	401.28218	U	I	KPNO	
401.298	401.30128	U	-	KPNO	
401.467	401.45374	U	-	KPNO	
401.493	401.48056	U	I	KPNO	
401.768	401.772	U	II	NIST	
401.916	401.899	U	II	NIST	
402.050	402.0252	Am	I	FT	
402.148	402.15421	Pu	II	BFG	
402.287	402.28249	U	I	KPNO	
402.498	402.50150	U	-	KPNO	
402.607	402.6023	U	II	SAO	
402.818	402.83296	U	I	KPNO	
402.966	402.95992	U	I	KPNO	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
403.135	403.1302	U	II	SAO	
403.464	403.44963	U	I	KPNO	
403.563	403.55270	Pu	I	BFG	d
403.650	403.6365	Am	II	FT	
403.693	403.68018	U	I	KPNO	
403.986	403.97436	U	I	KPNO	
404.290	404.27496	U	I	KPNO	
404.452	404.441	U	II	NIST	
404.772	404.76117	U	I	KPNO	
405.008	405.004	U	II	NIST	
405.202	405.19110	U	II	KPNO	
405.289	405.26102	U	-	KPNO	
405.289	405.3020	U	II	SAO	
405.443	405.430	U	II	NIST	
405.481	405.46731	U	I	KPNO	
405.522	405.54373	U	I	KPNO	
405.570	405.59400	U	I	KPNO	
405.824	405.819	U	II	NIST	
406.148	406.1347	U	I	SAO	
406.190	406.1753	U	II	SAO	
406.263	406.25440	U	II	KPNO	
406.321	406.30895	U	-	KPNO	
406.444	406.42698	U	I	KPNO	e
406.475	406.47692	Pu	II	BFG	e
406.636	406.62867	U	I	KPNO	
406.789	406.775	U	II	NIST	
406.887	406.87008	U	-	KPNO	
406.957	406.96455	U	I	KPNO	
407.022	407.00068	U	I	KPNO	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
407.246	407.22465	U	I	KPNO	
407.307	407.28318	U	I	KPNO	
407.370	407.35402	U	I	KPNO	
407.472	407.44843	U	II	KPNO	
407.676	407.669	U	II	NIST	
407.794	407.7785	U	I	SAO	
408.127	408.1217	U	I	KPNO	
408.240	408.23715	Pu	I	BFG	
408.309	408.30374	U	I	KPNO	
408.421	408.40966	U	I	KPNO	
408.516	408.49721	U	I	KPNO	
408.594	408.58489	Pu	I	BFG	
408.836	408.8252	U	II	SAO	
408.940	408.9291	Am	II	FT	
409.024	409.013	U	II	NIST	
409.174	409.14928	U	II	KPNO	
409.221	409.22229	Pu	I	BFG	
409.475	409.48906	U	II	KPNO	
409.526	409.52789	Pu	I	BFG	
409.582	409.57157	U	-	KPNO	
409.644	409.63501	U	I	KPNO	
409.708	409.71134	Pu	I	BFG	
409.806	409.78785	U	I	KPNO	
409.993	409.98362	Pu	II	BFG	
410.104	410.09230	Pu	II	BFG	
410.205	410.1905	U	I	SAO	
410.205	410.19577	Pu	I	BFG	
410.321	410.31126	U	I	KPNO	
410.641	410.638	U	II	NIST	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
410.705	410.6934	U	II	SAO	
410.842	410.8352	U	I	SAO	
411.112	411.10179	U	I	KPNO	
411.112	411.10701	Pu	I	BFG	
411.322	411.30898	Pu	II	BFG	
411.322	411.3113	U	II	SAO	
411.469	411.46092	U	I	KPNO	
411.495	411.49129	Pu	I	BFG	
411.573	411.57338	Pu	II	BFG	
411.617	411.610	U	II	NIST	
411.617	411.61268	Pu	II	BFG	
411.651	411.64658	Pu	II	BFG	e
411.693	411.69178	U	-	KPNO	e
411.693	411.71326	Pu	II	BFG	e
411.985	411.97908	Pu	I	BFG	
412.245	412.23566	U	I	KPNO	
412.311	412.29958	U	I	KPNO	
412.484	412.473	U	II	NIST	
412.526	412.51298	U	I	KPNO	
412.645	412.63357	U	I	KPNO	
412.747	412.73316	U	I	KPNO	
412.839	412.81146	Pu	I	BFG	
412.839	412.83344	U	II	KPNO	
412.839	412.85043	Pu	II	BFG	
412.941	412.92925	Pu	I	BFG	
413.072	413.06585	U	I	KPNO	
413.221	413.2010	U	I	SAO	
413.309	413.30052	Pu	I	BFG	e
413.327	413.3201	U	II	SAO	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
413.359	413.34914	U	I	KPNO	
413.507	413.51849	U	I	KPNO	
413.550	413.53011	Pu	I	BFG	
413.550	413.57553	U	II	KPNO	
413.612	413.59706	Pu	I	BFG	
413.666	413.64652	U	I	KPNO	
413.693	413.6813	U	II	SAO	
413.793	413.78692	U	I	KPNO	
413.918	413.91379	U	II	KPNO	
414.013	414.00413	Pu	I	BFG	
414.139	414.11951	Pu	II	BFG	
414.139	414.12615	U	I	KPNO	
414.200	414.18581	U	I	KPNO	
414.482	414.46955	U	II	KPNO	
414.675	414.66107	U	I	KPNO	
415.121	415.10914	Pu	I	BFG	
415.156	415.14434	Pu	I	BFG	
415.408	415.39710	U	I	KPNO	
415.488	415.47609	Pu	I	BFG	
415.548	415.54050	U	II	KPNO	
415.548	415.54562	Pu	I	BFG	
415.677	415.66483	U	I	KPNO	
416.001	415.99733	Pu	I	BFG	
416.103	416.0949	U	I	SAO	
416.204	416.19046	U	I	KPNO	
416.254	416.24288	U	I	KPNO	
416.381	416.368	U	II	NIST	
416.692	416.68633	U	I	KPNO	
416.785	416.77150	Pu	-	BFG	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
416.785	416.77709	Pu	I	BFG	
416.917	416.90469	U	I	KPNO	
416.917	416.95294	Pu	II	BFG	
417.091	417.09467	Pu	I	BFG	
417.168	417.159	U	II	NIST	
417.840	417.82760	Pu	II	BFG	
417.908	417.89960	U	II	KPNO	
418.035	418.03056	U	I	KPNO	
418.265	418.25103	Pu	I	BFG	
418.352	418.32569	U	I	KPNO	
418.352	418.35233	Pu	I	BFG	
418.500	418.47726	U	I	KPNO	
418.707	418.69601	U	I	KPNO	
418.823	418.80637	U	II	KPNO	
418.823	418.8121	Am	II	FT	
418.934	418.92733	U	II	KPNO	
419.010	418.98979	Pu	II	BFG	
419.010	419.00625	Pu	II	BFG	
419.079	419.09137	Pu	II	BFG	
419.199	419.19331	U	I	KPNO	
419.529	419.51799	U	I	KPNO	
419.629	419.62009	Pu	II	BFG	
419.629	419.62118	Pu	II	BFG	
419.836	419.82153	U	I	KPNO	
420.014	420.00861	U	II	KPNO	
420.124	420.1126	U	I	SAO	
420.283	420.29696	Pu	II	BFG	
420.435	420.4354	U	II	SAO	
420.576	420.55353	Pu	II	BFG	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
420.607	420.59321	Pu	I	BFG	
420.607	420.60888	U	I	KPNO	
420.659	420.63961	U	II	KPNO	
420.659	420.64807	Pu	I	BFG	
420.839	420.79874	Pu	II	BFG	
420.839	420.82336	Pu	I	BFG	
420.839	420.87241	Pu	II	BFG	
421.070	421.0441	U	II	SAO	
421.176	421.1658	U	II	SAO	
421.240	421.22470	U	-	KPNO	
421.401	421.38644	U	I	KPNO	
421.444	421.4411	U	II	SAO	
421.539	421.52226	Pu	II	BFG	
421.539	421.52881	U	I	KPNO	
421.560	421.55015	U	I	KPNO	
421.603	421.59858	U	I	KPNO	
421.794	421.77561	U	I	KPNO	
421.916	421.89889	Pu	II	BFG	
422.010	421.99631	U	I	KPNO	
422.206	422.18707	Pu	I	BFG	
422.253	422.237	U	I	NIST	
422.425	422.40890	Pu	I	BFG	
422.425	422.41973	Pu	I	BFG	
422.446	422.43623	U	I	KPNO	
422.539	422.53671	U	II	KPNO	
422.680	422.6728	Ca	I	NIST	
423.182	423.16679	U	I	KPNO	
423.208	423.2043	U	II	SAO	e
423.326	423.31321	U	I	KPNO	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
423.408	423.40593	U	-	KPNO	
423.465	423.45298	U	-	KPNO	
424.174	424.14634	U	I	KPNO	
424.447	424.437	U	II	NIST	
424.638	424.62602	U	I	KPNO	
424.725	424.72252	Pu	I/II	BFG	f
424.984	424.97135	Pu	II	BFG	
425.146	425.13996	U	I	KPNO	
425.260	425.24260	U	II	KPNO	
425.377	425.38524	U	I	KPNO	
425.788	425.77859	Pu	II	BFG	
426.195	426.18858	Pu	I	BFG	
426.569	426.5550	Am	I	FT	
426.640	426.6323	U	I	SAO	
426.737	426.72987	U	II	KPNO	
426.804	426.79736	U	-	KPNO	
426.894	426.88474	U	II	KPNO	
426.973	426.96054	U	II	KPNO	
426.973	426.97690	Pu	I	BFG	
427.132	427.12287	U	I	KPNO	
427.340	427.33368	Pu	II	BFG	
427.408	427.39709	U	II	KPNO	
427.500	427.49306	U	I	KPNO	
427.662	427.6463	U	II	SAO	
427.841	427.83310	Pu	II	BFG	
427.870	427.87432	Pu	II	BFG	e
427.961	427.93230	U	I	KPNO	
428.029	428.02551	Pu	II	BFG	
428.078	428.06507	U	I	KPNO	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
428.128	428.11692	Pu	I	BFG	
428.218	428.2023	U	II	SAO	
428.257	428.24608	U	II	KPNO	
428.393	428.38996	U	I	KPNO	
428.803	428.7861	U	II	SAO	
428.900	428.8831	U	I	SAO	
428.900	428.90808	Pu	II	BFG	
428.900	428.91849	Pu	II	BFG	
428.944	428.9258	Am	I	FT	
429.084	429.08753	U	II	KPNO	
429.337	429.32928	U	I	KPNO	
429.526	429.50974	U	I	KPNO	
429.725	429.7105	U	II	SAO	
429.805	429.77992	Pu	II	BFG	
429.805	429.81989	Pu	II	BFG	
429.952	429.94139	U	-	KPNO	
430.049	430.08727	Pu	I	BFG	
430.157	430.14640	U	II	KPNO	
430.270	430.26257	U	-	KPNO	
430.690	430.67360	U	-	KPNO	
430.931	430.91675	U	I	KPNO	
430.978	430.96885	U	I	KPNO	
431.097	431.07058	Pu	I	BFG	
431.331	431.30790	U	I	KPNO	
431.382	431.3874	U	II	SAO	
431.670	431.64822	U	I	KPNO	
431.670	431.65852	Pu	II	BFG	
431.704	431.70694	U	I	KPNO	
432.247	432.23823	U	I	KPNO	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
432.379	432.37754	U	I	KPNO	
432.473	432.4570	Am	II	FT	
432.602	432.5889	U	II	SAO	
432.881	432.87305	U	I	KPNO	
433.065	433.05830	Pu	II	BFG	
433.535	433.52702	U	I	KPNO	
433.581	433.5732	U	I	SAO	
433.581	433.60111	Pu	II	BFG	
433.724	433.71742	Pu	II	BFG	e
433.759	433.73975	U	I	KPNO	
434.181	434.16865	U	II	KPNO	
434.741	434.71955	U	II	KPNO	
435.284	435.27081	Pu	II	BFG	
435.468	435.4546	U	I	SAO	
435.586	435.57400	U	I	KPNO	
435.811	435.80670	Pu	II	BFG	
436.222	436.22143	U	I	KPNO	
436.302	436.2928	U	II	SAO	
436.711	436.73668	Pu	II	BFG	
436.751	436.74063	Pu	I	BFG	
437.194	437.1758	U	I	SAO	
437.263	437.27557	U	I	KPNO	
437.354	437.3407	U	II	SAO	
437.995	437.99035	Pu	II	BFG	
438.016	438.02653	U	II	KPNO	
438.130	438.12308	Pu	I/II	BFG	f
438.242	438.23360	U	I	KPNO	
438.344	438.3262	U	I	SAO	
438.344	438.35692	Pu	II	BFG	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
438.538	438.53465	Pu	II	BFG	
439.226	439.20846	Pu	I	BFG	
439.261	439.28840	Pu	II	BFG	
439.366	439.359	U	I	NIST	
439.366	439.39234	Pu	II	BFG	
439.633	439.64458	Pu	II	BFG	
440.261	440.26029	U	I	KPNO	
440.500	440.48942	Pu	I	BFG	
440.590	440.59518	U	II	KPNO	
440.680	440.67788	Pu	II	BFG	
440.789	440.79539	U	II	KPNO	
441.489	441.47263	Pu	I	BFG	
441.536	441.5239	U	II	SAO	
441.854	441.84725	U	I	KPNO	
441.961	441.94413	Pu	II	BFG	
442.055	442.04018	U	I	KPNO	
442.302	442.29852	U	II	KPNO	
442.557	442.54089	U	I	KPNO	
442.709	442.69346	U	I	KPNO	
442.769	442.7651	U	II	SAO	
442.971	442.96123	U	II	KPNO	
443.021	443.00808	U	I	KPNO	
443.298	443.29987	Pu	II	BFG	
443.390	443.37711	Pu	I	BFG	
443.390	443.3887	U	II	SAO	
443.471	443.4531	U	II	SAO	
443.505	443.49009	U	-	KPNO	
443.907	443.91172	Pu	I	BFG	
444.054	444.03361	Pu	II	BFG	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
444.088	444.0737	U	I	SAO	
444.139	444.1357	Am	II	FT	
444.156	444.16496	Pu	II	BFG	
444.725	444.70407	U	I	KPNO	
444.845	444.82656	Pu	II	BFG	
444.845	444.83307	U	I	KPNO	
444.913	444.89782	U	I	KPNO	
445.149	445.14935	U	I	KPNO	
445.333	445.31442	Pu	I	BFG	
445.603	445.59067	Pu	I	BFG	
445.692	445.67061	Pu	II	BFG	
445.760	445.74521	U	I	KPNO	
445.881	445.87015	U	I	KPNO	
446.112	446.09272	U	II	KPNO	
446.156	446.14449	U	I	KPNO	
446.306	446.29681	U	II	KPNO	
446.530	446.5138	U	II	SAO	
446.842	446.85389	Pu	II	BFG	
446.942	446.9325	U	I	SAO	
447.244	447.23026	U	I	KPNO	
447.287	447.27884	Pu	II	BFG	
447.287	447.28390	Pu	II	BFG	
448.441	448.44369	Pu	I	BFG	
449.089	449.08316	U	II	KPNO	
449.297	449.30408	U	II	KPNO	
449.391	449.37819	Pu	II	BFG	
449.476	449.47120	U	I	KPNO	
450.510	450.49165	Pu	II	BFG	
450.675	450.66733	Pu	I	BFG	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
450.943	450.9450	Am	II	FT	
451.025	451.0317	U	II	SAO	
451.060	451.05662	Pu	II	BFG	
451.164	451.17151	U	II	KPNO	
451.294	451.28791	Pu	II	BFG	
451.541	451.52772	U	II	KPNO	
451.682	451.67231	U	I	KPNO	
453.632	453.61461	Pu	II	BFG	
453.826	453.81876	U	II	KPNO	
454.379	454.36255	U	II	KPNO	
454.573	454.55964	U	I	KPNO	
455.174	455.15739	Pu	II	BFG	
455.207	455.1975	U	I	SAO	
455.393	455.3852	U	II	SAO	
455.526	455.5091	U	II	SAO	
456.395	456.36074	U	I	KPNO	
456.672	456.66248	Pu	I	BFG	
456.745	456.73114	U	-	KPNO	
457.007	456.991	U	II	SAO	
457.368	457.36797	U	II	KPNO	
457.557	457.5590	Am	II	FT	
457.684	457.66400	U	I	KPNO	
457.991	457.97355	Pu	II	BFG	
458.497	458.4851	U	II	SAO	
459.340	459.3307	Am	II	FT	
460.118	460.11281	U	II	KPNO	
460.384	460.36586	U	II	KPNO	
460.524	460.51487	U	II	KPNO	
460.721	460.70154	Pu	I	BFG	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
461.164	461.14328	U	-	KPNO	
462.041	462.02765	U	I	KPNO	
462.503	462.48170	Pu	I	BFG	
462.725	462.74053	Pu	II	BFG	
462.756	462.74574	Pu	II	BFG	e
463.115	463.08579	Pu	II	BFG	
463.177	463.16154	U	I	KPNO	
463.954	463.92902	Pu	II	BFG	
464.181	464.1650	U	II	SAO	
466.158	466.16454	U	I	KPNO	
466.287	466.2790	Am	I	FT	
466.389	466.3748	U	I	SAO	
466.389	466.42199	Pu	II	BFG	
466.691	466.68512	U	II	KPNO	
467.159	467.13980	U	II	KPNO	
467.658	467.65170	Pu	I	BFG	
468.119	468.12791	U	I	KPNO	
468.176	468.1651	Am	I	FT	
468.922	468.90738	U	II	KPNO	
468.972	468.95879	Pu	I/II	BFG	g
469.532	469.52220	U	I	KPNO	
470.139	470.13362	Pu	II	BFG	
470.199	470.20380	U	II	KPNO	
470.270	470.25122	U	II	KPNO	
470.695	470.6802	Am	I	FT	
471.464	471.45846	U	I	KPNO	
471.591	471.56689	U	I	KPNO	
472.286	472.27168	U	II	KPNO	
473.127	473.12056	Pu	II	BFG	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
473.176	473.15941	U	II	KPNO	
473.541	473.54042	Pu	I	BFG	
475.687	475.68441	U	-	KPNO	
476.737	476.71698	Pu	II	BFG	
476.879	476.86642	U	I	KPNO	
477.350	477.34331	U	I	KPNO	
477.783	477.76772	U	I	KPNO	
477.783	477.78623	Pu	I	BFG	
477.832	477.80956	U	I	KPNO	
477.832	477.83184	Pu	I	BFG	
477.980	477.9628	U	II	SAO	
478.033	478.01911	U	I	KPNO	
478.316	478.30792	U	-	KPNO	
478.610	478.59201	U	I	KPNO	
479.025	479.00997	U	I	KPNO	
479.928	479.90989	Pu	I	BFG	
480.899	480.88415	U	II	KPNO	
480.899	480.89335	Pu	II	BFG	
481.105	481.08889	U	I	KPNO	
481.465	481.44477	Pu	I	BFG	
481.582	481.57072	U	I	KPNO	
481.953	481.95490	U	II	KPNO	
482.329	482.31721	Pu	II	BFG	
484.248	484.22892	Pu	II	BFG	
485.677	485.66560	U	I	KPNO	
485.823	485.8090	U	II	SAO	
486.893	486.8858	U	I	SAO	
487.859	487.85013	U	I	KPNO	
488.040	488.05715	Pu	II	BFG	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
488.526	488.5141	U	I	SAO	
489.437	489.42526	Pu	II	BFG	
489.457	489.44196	Pu	I	BFG	
489.944	489.93753	U	I	KPNO	
491.052	491.03518	U	I	KPNO	
491.188	491.16693	U	II	KPNO	
491.188	491.17407	Pu	I	BFG	
491.335	491.31690	U	II	KPNO	
491.693	491.68760	U	I	KPNO	e
491.710	491.70558	Pu	II	BFG	
492.863	492.8447	U	I	SAO	
495.589	495.59035	U	I	KPNO	
496.542	496.53541	U	I	KPNO	
496.750	496.73226	U	I	KPNO	
496.954	496.94721	Pu	I	BFG	
496.988	496.97664	Pu	I	BFG	
498.698	498.68479	Pu	I	BFG	
498.698	498.68977	U	II	KPNO	
498.949	498.93420	Pu	I	BFG	
499.087	499.0786	Am	I	FT	
500.843	500.82101	U	II	KPNO	
501.160	501.1409	U	I	SAO	
502.358	502.33199	Pu	II	BFG	
502.757	502.73841	U	I	KPNO	
504.478	504.46324	Pu	I	BFG	
504.478	504.466	Np	I	NIST	
506.392	506.37576	U	I	KPNO	
508.861	508.82861	U	I	KPNO	
511.584	511.56686	Pu	I	BFG	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
516.054	516.06678	U	I	KPNO	
516.424	516.414	U	I	NIST	
517.449	517.46783	U	I	KPNO	
518.094	518.08773	U	I	KPNO	
518.388	518.38910	Pu	I	BFG	
519.166	519.15129	U	I	KPNO	
519.395	519.37253	Pu	I	BFG	
520.525	520.51622	U	I	KPNO	
520.991	520.96566	Pu	II	BFG	f
521.708	521.69334	U	I	KPNO	
524.790	524.76433	U	I	KPNO	b
525.442	525.42395	Pu	I	BFG	
528.040	528.05381	U	I	KPNO	
530.440	530.44104	Pu	I	BFG	
530.734	530.71584	Pu	I	BFG	
530.873	530.85412	U	I	KPNO	
531.166	531.1879	U	II	SAO	
532.949	532.9241	U	I	SAO	
534.177	534.18514	Pu	II	BFG	
536.424	536.41015	Pu	I	BFG	
538.092	538.10125	Pu	I	BFG	
540.272	540.2619	Am	I	FT	
542.486	542.4698	Am	I	FT	
548.250	548.20597	Pu	I	BFG	
548.250	548.253	U	II	NIST	
549.311	549.29509	U	II	KPNO	
549.872	549.84972	Pu	I	BFG	
551.056	551.07146	Pu	I	BFG	
556.221	556.20587	Pu	I	BFG	

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
556.431	556.41708	U	I	KPNO	
557.068	557.05125	Pu	I	BFG	
557.068	557.06636	U	II	KPNO	
559.071	559.05436	Pu	I	BFG	
559.245	559.23281	Pu	I	BFG	
559.839	559.8129	Am	I	FT	
561.106	561.0890	U	I	SAO	b
562.063	562.04761	U	II	KPNO	e
566.775	566.75790	Pu	I	BFG	
570.972	570.96202	Pu	I	BFG	
573.346	573.31898	Pu	I	BFG	
579.853	579.853	U	II	NIST	
580.225	580.2106	U	I	SAO	
583.623	583.602	U	I	NIST	
583.929	583.90480	Pu	I	BFG	
585.432	585.37505	Pu	I	BFG	
585.432	585.3903	U	II	SAO	
586.512	586.49235	Pu	I	BFG	
589.350	589.31335	Pu	I/II	BFG	f
597.170	597.15010	U	I	KPNO	b
597.649	597.63214	U	I	KPNO	
597.900	597.89043	Pu	I	BFG	
598.348	598.33479	Pu	I	BFG	
598.633	598.61002	U	I	KPNO	
599.756	599.73103	U	I	KPNO	
601.290	601.27772	Pu	I	BFG	
610.044	610.05240	Pu	I	BFG	
611.965	611.94260	Pu	I	BFG	
612.983	612.97233	U	I	KPNO	b

Observed Wavelength (nm)	Literature Wavelength (nm)	Element	Ionic State	Reference	Notes
613.272	613.2620	U	I	SAO	
617.226	617.186	U	I	NIST	
619.305	619.27976	Pu	I	BFG	
629.358	629.3328	U	I	SAO	
630.487	630.46613	Pu	I	BFG	
640.508	640.5105	Am	I	FT	b
644.933	644.91607	U	I	KPNO	
645.000	644.97438	Pu	I	BFG	
646.523	646.49842	U	I	KPNO	
648.694	648.67070	Pu	I	BFG	
648.917	648.88530	Pu	I	BFG	
660.919	660.89473	Pu	I	BFG	
662.824	662.80457	Pu	I	BFG	
682.701	682.69133	U	I	KPNO	
688.781	688.77096	Pu	I	BFG	
701.896	701.891	Np	I	NIST	

