γ emission from the 31-yr isomer of ^{178}Hf induced by x-ray irradiation

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(Received 16 April 1999; revised manuscript received 18 October 1999; published 18 April 2000)

A sample containing 6.3×10^{14} nuclei of the 16^+ isomer of ^{178}Hf having a half life of 31 years and excitation energy of 2.446 MeV was irradiated with x-ray pulses derived from a device operated at 15 mA to produce bremsstrahlung radiation with an end point energy set to be 63 keV. Gamma spectra of the isomeric target were taken with two independent Ge detectors. Intensities of the 213.4 keV ($4^+\rightarrow2^+$) and 325.5 keV ($6^+\rightarrow4^+$) transitions in the ground state band of ^{178}Hf were found to increase when irradiated. The largest enhancement was $1.6\pm0.3\%$ measured in the 213.4 keV transition. Such an accelerated decay of the ^{178}Hf isomer is consistent with an integrated cross section exceeding $2.2\times10^{-22}\,\mathrm{cm}^2\,\mathrm{keV}$ if the resonant absorption takes place below 20 keV as indicated by the use of selective absorption filters in the irradiating beam.

PACS number(s): 25.20.Lj, 27.70.+q, 21.10.Ma, 21.90.+f

I. INTRODUCTION

The four- and five-quasiparticle isomers of Lu, Hf, and Ta are interesting because they have relatively long lifetimes for states with 2 to 3 MeV excitation energies. They are termed *K* isomers because spontaneous radiative decay is hindered by structural changes forbidden by *K*-quantum numbers. In this mass region the nuclei are deformed and the projection of the total angular momentum upon the symmetry axis contributes this quantum number, *K*, which should change during a radiative transition by no more than the multipolarity of the mediating moment. Transitions from the high-*K* isomer to the rotational states of a low-*K* band are ''forbidden,'' and so relatively long lifetimes are inevitable. The most interesting example may be the 31-yr, four-quasiparticle isomer ^{178}Hf having 2.446 MeV excitation energy.

Proposals to trigger the release of the energy of a nuclear isomer by exciting it to some higher level associated with freely radiating states have been known for over a decade [1]. To be efficient such schemes require the existence at an energy near that of the isomer of a state of mixed *K*. It was proposed [1] to use the resonant absorption of x rays from a bremsstrahlung source to excite some fraction of a high-*K* isomeric population to the *K*-mixing level. Then, the decay to the ground state via one or more γ cascades could subsequently release the total energy of the isomer plus that of the absorbed trigger photon. The types of *K*-mixing states needed in such schemes to induce the decay of nuclear isomers have been reported [2] in ^{180}Ta and described in ^{174}Hf and other isomers [3].

In 1999 the use of soft x-ray irradiation to accelerate the decay of the ^{178}Hf isomer was reported [4,5]. A $4\pm2\%$ increase of emission in the ground state band (GSB) was observed when the bremsstrahlung component of the irradiating spectrum had an endpoint energy of 90 keV. It was straightforward to compute from the size of the effect, the number of isomeric nuclei, and the irradiating flux at various energies, that the integrated cross section (ICS) would be of unprecedented magnitude for the excitation of the isomeric state to an intermediate state able to decay by subsequent cascade toward the GSB. In that work the continuous x-ray spectrum was most intense in the range of 20 to 50 keV, and while the particular components causing the transition which initiated the process were not determined, excitation by any of them would have given a large value for the corresponding ICS.

At such low energies, the perceptions of Mossbauer spectroscopy may be followed to yield an expected photon-absorption cross section and resonance shape given by the

Breit-Wigner expression. At 20 keV a $\sigma\Gamma \approx 10^{-22}\,\mathrm{cm}^2\,\mathrm{keV}$ would suggest a width of about 50.0 meV. While still smaller than the 0.5 eV width deduced for the deexcitation of ^{180}Ta induced by photons, the systematics for the nuclear transition strengths do not predict such large widths corresponding to short lifetimes ($\sim 10^{-15}\,\mathrm{s}$) as being typical for nuclear levels at $E^* = 2$–3 MeV. For example, the recommended calculations of the reduced transition probabilities, $B(E1)$ and $B(E2)$, give $\sigma\Gamma \approx 3\times 10^{-27}\,\mathrm{cm}^2\,\mathrm{keV}$ for ^{180}Ta, a prediction two orders of magnitude lower than the experimental value [2,6,7]. The corresponding disagreement may be even more pronounced in the ^{178}Hf case, mainly because of the paucity of accepted levels with appropriate quantum numbers for the decay of the high-spin intermediate state excited after the absorption of a photon by the $^{178}\mathrm{Hf}^{m2}$ isomer. As a consequence, the properties of intermediate K-mixing states appear as an extraordinary issue which naturally excites more focused studies. In particular, more details on the acceleration of the decay of the $^{178}\mathrm{Hf}^{m2}$ isomer are required in order to clarify the mechanism of the x-ray induced deexcitation of the isomer. By focusing upon a confirmation of the work previously reported [4,5], while extending it to include a study of a fragment of a cascade not present in the spontaneous decay of the isomer; the present work is aimed at meeting these requirements.

II. EXPERIMENTAL DETAILS

The experimental work was performed at the Center for Quantum Electronics, University of Texas at Dallas. The irradiating beam consisted of the bremsstrahlung radiation provided by an x-ray unit operated at 15 mA. In the work previously reported [4,5] 90 kV was applied to the anode of the x-ray diode, so that the x-ray output was a mixture of lines and bremsstrahlung continuum having end point energy of 90 keV. The scattering of photons from the irradiating beam into the detectors used to collect the γ-ray emission from the samples was a major source of noise. For the experiments reported here, the anode voltage was reduced to 63 kV and scattered x rays were absorbed by a 1 mm thick shielding of Cd that had negligible effect upon the characteristic gamma lines with energies greater than 200 keV emitted by the decaying $^{178}\mathrm{Hf}^{m2}$ isomeric nuclei. The x-ray device was operated in a pulsed mode at 60 Hz that ensured a duty cycle for the irradiation of about 0.6%.

The irradiated sample consisted of a sealed plastic target containing 6.3×10^{14} $^{178}\mathrm{Hf}^{m2}$ isomeric nuclei placed in a 1 cm diameter well. The main radiative contaminants in the sample were the ^{172}Hf nucleus and its daughters at a level comparable to the intensity of the 31-yr spontaneous decay of the ^{178}Hf isomer. The sample was placed at 5.5 cm distance from the emission point of the x rays, and the only absorption was due to the glass of the x-ray tube and the 2 mm plastic sealing of the x-ray device. The absorption in the sealing of the sample was negligible.

In Fig. 1 we show the experimental arrangement. Two independent 10% coaxial Ge detectors were placed at a nominal 20 cm from the isomeric target positioned for irradiation. In addition to the general isolation of the detector location by the Cd shield, each Ge detector was closely fitted with a 2 mm thick Cu shield. The resulting counting rate of the target was nominally 15 kcps, increasing by another 200 cps when the x-ray irradiation was present. In this arrangement signals from the two Ge detectors were amplified and then outputs were fanned out to 2 ADC's with $8K$ channels and 2 ADC's with $2K$ channels, respectively. Optimization of pole-zero adjustments produced nominal resolution of less than 2.0 keV at 213 keV for each detector.

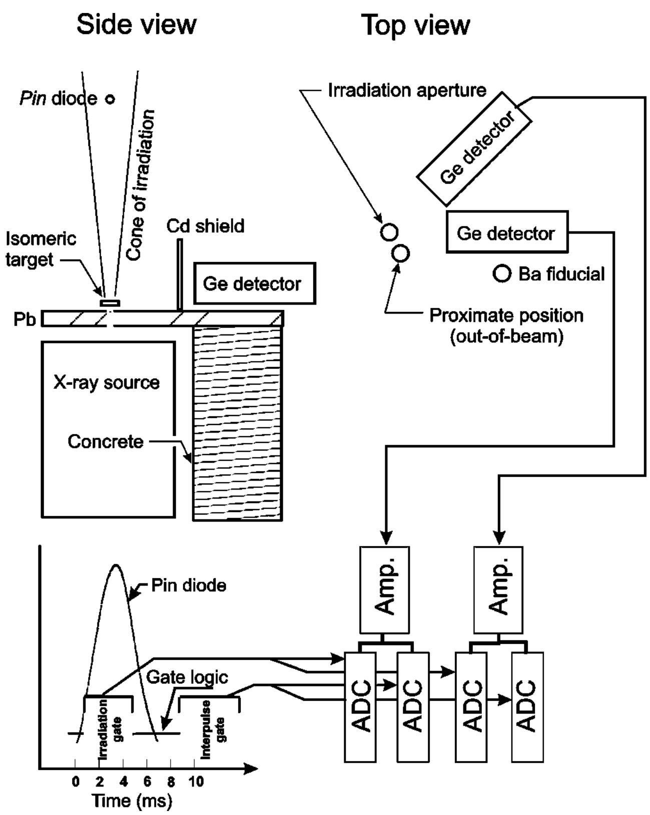

FIG. 1. Schematic drawing of the experimental arrangement showing the geometric placements and dimensions of the components, together with timing and arrangement of the electronics.

Data acquisition was enabled only when a signal provided by a *p-i-n* diode which monitored the x-ray beam was present. The signal from the *p-i-n* diode produced a trigger pulse at a level selected to correspond to an early (<0.25 ms) time after onset of the pulse of irradiation. That trigger was used to produce two gates, one of 4 ms duration beginning at the time of triggering and the other of 5 ms duration beginning 8 ms after trigger. Onset of the next pulse of irradiation occurred at 16.67 ms after triggering, and the cycle repeated. Intervals were counted from a 20 MHz clock. As shown in Fig. 1, the first gate corresponded to the period during which the x rays were of significant intensity while the second coincided with the interpulse time during which current to the x-ray tube was turned off. One of each of the two gates were used to enable one of each of the two $2K$ and $8K$ ADC's, so that counts were collected during irradiated and quiescent times by ADC's with each of the available values of resolution. Since the $8K$ ADC's serviced data from one of the Ge detectors and the $2K$ ADC's the other, we had

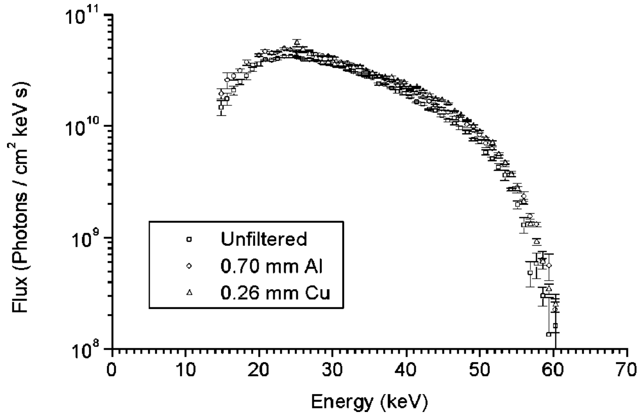

FIG. 2. Graph of the x-ray spectral flux expected at the inbeam position of the isomeric target. These experimental data for a 63 keV endpoint were measured with a Ge detector from input attenuated with a pin hole and placed at 12 m distance from the x-ray tube.

available two completely independent measurement systems for observing the triggered decay of the isomeric nuclei. Such an experimental arrangement resulted in a value of the total dead time of the acquisition chain of about 20% during the irradiation. The energy and efficiency calibration of the Ge detectors was done using standard calibration sources ^{60}Co, ^{133}Ba, and ^{137}Cs. We estimated the maximum absolute detection efficiency of about 0.9×10^{-3} to correspond to a γ-ray energy of 150 keV. We recorded γ-ray energies up to 1.6 MeV with amplification set to give 0.2 keV/channel with the $8K$ ADC, allowing for a good analysis of the possible contamination of the lines of interest. Spectra have been stored each two hours and gain matched in software using internal γ lines before adding them. The shielding of the Ge detector inhibited collection of spectral data for transition energies below about 100 keV.

Special attention was devoted to the measurement of the x-ray flux emitted by the x-ray device during operation at 63 kV. For this purpose we placed one of the Ge detectors at 12.0 m distance from the x-ray device. The direct x-ray flux could reach the active area of the detector only through a 1 mm diameter hole placed at 0.5 cm from the detector. High counting rates still required the application of absorbers. From a few measurements with different absorbers the final spectra could be reconstructed; it is shown in Fig. 2 after corrections were made for the absorption of the lower energy components by air in the path. One can see in Fig. 2 that there is an intensity, about 5×10^{10} photons cm^{-2} keV^{-1} s^{-1} at low energies near 20 keV; and a drastic decrease of the intensity to higher E_x values. These peculiarities of the incident radiation are important for the estimation of the cross section integral, as discussed below. The definition of the flux values for $E>30$ keV is reliably indicated by the statistical uncertainties shown in Fig. 2. However, below 20 keV absorptions required such large corrections to be applied to such small numbers of counts actually acquired that the values shown in Fig. 2 may contain more uncertainty for $E<20$ keV than is shown. Uncertainties in establishing the absolute scale of Fig. 2 as great as 30% are also possible.

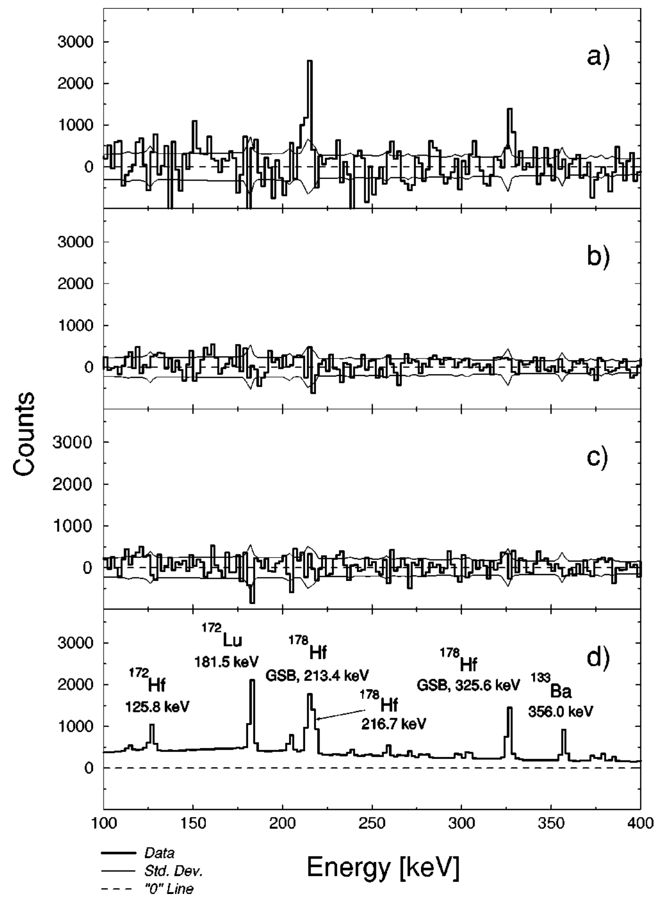

FIG. 3. Plot of the differences in counts (a), (b), and (c) obtained in the spectrum of the ^{178}Hf from the isomeric target in comparison to 1% of the reference data shown in (d). Data were acquired with the detector connected to the $8K$ ADC's and differences were computed by subtracting from the data scaled spectra taken without irradiation. In this region which includes the 325.5 keV $(6^+ \to 4^+)$ component of the GSB of ^{178}Hf, normalization could be verified by comparing the areas under the 356.0 keV line of ^{133}Ba. The spectra are (a) target inbeam, (b) target inbeam with 0.7 mm thick Al filter interposed in beam, and (c) target outbeam. Prominent spectral lines are identified in (d), and minor lines correspond to components of the spontaneous decay of either ^{178}Hf^m or ^{172}Lu and its daughters.

III. RESULTS

Acquired with the 10% coaxial Ge detectors, spectra of the induced emission of γ radiation generally resembled those obtained in the earlier work [4,5]. However, in the present experiment an additional reference source, ^{133}Ba was included. It was not irradiated, but was positioned in proximity to the Ge detector driving the $8K$ ADC's. Its fiducial lines were within about 30 keV of the 325.5 keV $(6^+ \to 4^+)$ component of the GSB, and so allowed us to monitor effects on that member of the GSB of drift or nonlinear de-

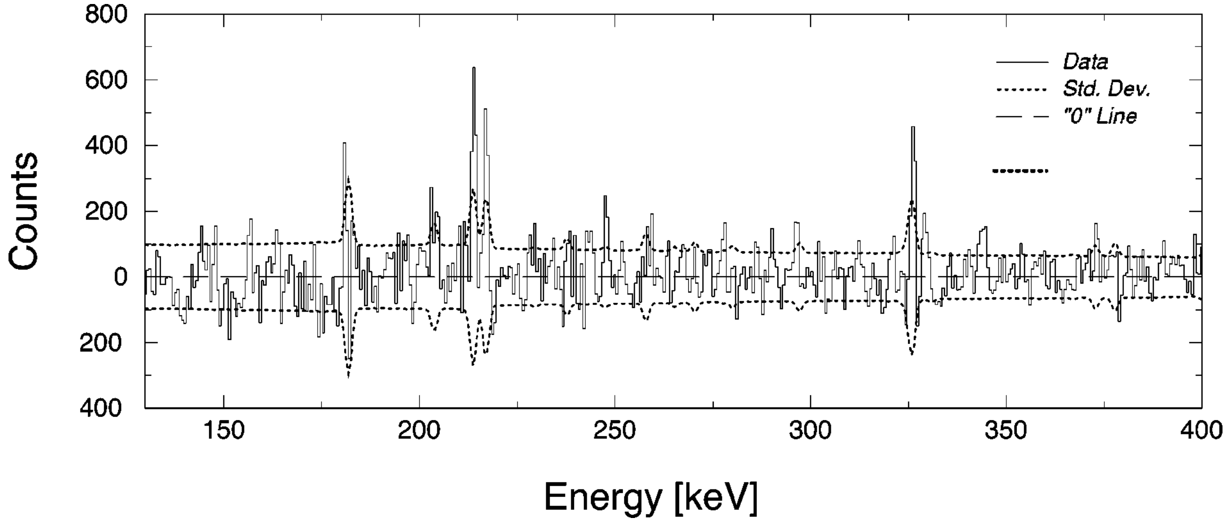

FIG. 4. Plot of the differences in counts obtained in the spectrum of the ^{178}Hf from the isomeric target acquired with the detector connected to the 2K ADC's. Curves showing computed values for 1σ for the differences are shown by the dotted lines.

pendence of efficiency upon energy. In addition, an empty target holder, the ''blank,'' of similar mass and construction to the one carrying the isomeric nuclei was available for use. Comparative measurements showed that over 95% of the elastic and inelastic scattering of the irradiating beam arose from the mass of the holder and not its contents. Spectra of the scattering from the mass of the holder appeared featureless and completely limited to energies below the endpoint of the bremsstrahlung, e.g., 63 keV.

Three geometric arrangements were important during the collection of data. (1) ''Inbeam'' in which the isomeric target was centered in the cone of irradiation as shown in Fig. 1, (2) ''filtered'' which was the same as (1) except that a foil of 0.7 mm thickness of pure Al was interposed in the irradiating beam, and (3) ''outbeam'' in which the target was placed out of the beam of x rays at the position denoted as ''proximate'' in Fig. 1, and the ''blank'' target holder replaced it in the cone of irradiation without any filters. In each arrangement, data acquisitions were gated by the pulses corresponding to the 4 ms period of irradiation (active gate) or by the pulses corresponding to the 5 ms of interpulse time during which the irradiation was ''off'' (passive gate). During analysis both inbeam and outbeam results were scaled to the spectra acquired during the 5 ms interpulse gate by normalizing the total number of counts collected in each spectra, excluding only the few of the lower channels containing the additional 200 cps of scattered x rays from the irradiating beam. Scaled in this way, it was observed that the areas of the fiducial line in each spectra were the same and that the values of scaling factor never varied by more than 0.07%. The effects of irradiation were determined by subtracting the spectra made with the passive gate from one made with the active gate.

Figure 3 shows the results of about 3 days of acquisition time for each spectrum, during which there were about 700 sec of actual counting time enabled by the gate coincident with the detection of x rays. From top to bottom are shown the different spectra taken during the variations of inbeam, filtered, and outbeam conditions as discussed above. They are compared with the raw spectrum divided by 100 in order to give some scale for the comparison. The differences in total gross counts in the channels corresponding to the relevant peaks are summarized in Tables I, II, and III. Shown in the tables are the actual counts acquired, while data in the panels in Fig. 3 have been scaled further from top to bottom by factors of 1.6928(10), 0.9401(5), 1.0, and 0.01, respectively, to take into account the different storage times.

TABLE I. Comparison of the γ emission from the target irradiated in the inbeam position with the values obtained without irradiation. Data are presented as gross counts collected in channels which span the position of the corresponding line and were normalized as detailed in the text.

$E\gamma$ (keV)	Nucleus	With irradiation counts	Baseline Counts	Baseline Norm.[a] counts	Excess (counts)
181.6	^{172}Lu	238396 (488)	303010 (550)	238226 (458)	170 (669)
213.5/216.7	^{178}Hf GSB	214347 (463)	268794 (518)	211326 (429)	3021 (631)[b]
325.5	^{178}Hf GSB	152455 (390)	191786 (438)	150782 (357)	1637 (529)[c]
356.0	^{133}Ba	90288 (300)	114604 (339)	90102 (273)	186 (405)

[a]Verified by the 356 keV line of ^{133}Ba.
[b]Estimation of the effect: $2.05\pm0.43\%$ of the area of the corresponding line.
[c]Estimation of the effect: $1.82\pm0.58\%$ of the area of the corresponding line.

TABLE II. Comparison of the γ emission from the target irradiated in the inbeam position through the 0.7 mm Al foil with the values obtained without irradiation. Data are presented as gross counts collected in channels which span the position of the corresponding line and were normalized as detailed in the text.

$E\gamma$ (keV)	Nucleus	With irradiation counts	Baseline Counts	Baseline Norm.[a] counts	Excess (counts)
181.6	^{172}Lu	428136 (654)	545210 (738)	428535 (620)	−399 (901)
213.5/216.7	^{178}Hf GSB	381005 (617)	484935 (696)	381159 (580)	−154 (847)
325.5	^{178}Hf GSB	273201 (523)	346844 (589)	272619 (483)	582 (712)
356.0	^{133}Ba	161636 (402)	205939 (454)	161868 (366)	−232 (544)

[a]Verified by the 356 keV line of ^{133}Ba.

General observations drawn from Fig. 3 followed those of previous reports [4,5] which suggested that not all components of the spontaneous decay cascade were enhanced by the x rays, but rather that the lower members of the GSB were the ones enhanced by the accelerated decay of the isomeric nuclei caused by the x-ray irradiation. This observation was confirmed by the data from the other independent Ge detector. Figure 4 shows the comparable results taken with the $2K$ ADC system. About the same fraction of enhancement can be seen in the 213.4 keV ($4^+\rightarrow 2^+$) and 325.5 keV ($6^+\rightarrow 4^+$) components of the GSB. The lowest member corresponding to ($2^+\rightarrow 0^+$) at 93.2 keV could not be included in the study because of the attenuation caused by the Cd filter. The counts in the channels for the relevant peaks are summarized in Table IV as detected with the $2K$ ADC's.

If several of the transitions feeding the GSB in spontaneous decay are not enhanced, the question naturally arises as to the channels followed by the induced decay of the isomer before they feed into the GSB. A search through the spectra suggested several ''new'' components. Figure 5 shows the best of such lines observed in the experiment reported here. These data were taken with the endpoint energy of the x rays raised to 90 keV. In this case the detrimental effects of the greater scattering background were suppressed by additional absorbers while the effect was proportional to the higher intensities. The line at 210.3 keV is close to a member of the $K^\pi=6^+$ band known to ^{178}Hf but not previously seen in spontaneous decay of the isomer. The fitting shown in the figure corresponds to 1080 counts. In a reference baseline spectrum this line would be coincident with a known ^{172}Lu line, the intensity of which can be scaled from the fitting to the 203.4 keV line using standard tabulations of intensities [8]. From these established intensities, the contribution from the ^{172}Lu to the 1080 counts seen in the irradiated spectrum must be less than 160 counts. The line at 546.2 keV can be seen even more clearly in Fig. 6 because it is not found on the wings of a larger line. The fitted area shown in the figure corresponds to 262 counts and so, to 3 to 4σ, since there are neither observed nor expected structures in the reference spectrum within several linewidths of the center. Lines corresponding to other transitions, feeding and fed, by the 210.3 and 546.2 keV line may be present in our data, but statistics have not been sufficient to confirm a proposed scheme of decay induced by the x-ray irradiation.

IV. DISCUSSIONS AND CONCLUSION

The first reports [4,5] of the great efficiency with which low energy x rays could induce the decay of the ^{178}Hf^{m2} isomer, stressed all models which might have been able to predict such an effect [9–12]. The problem has not been completely resolved by the results of the experiment reported here. However, some illumination of the unexpected nature of the phenomenon has been realized. Because it tends to bring a convergence with systematics of the nuclear transition strengths, it is instructive to examine the details.

Of first importance is that the general phenomenology has been reproduced in accordance with Refs. [4,5]. Tables I and IV show that the same type of small x-ray generator traditionally used in dental medicine can be used to induce enhancements of the order of 2% in the rates of spontaneous decay of the Hf isomer. Tables I and IV present completely independent measurements of the effect made from separate instrumental platforms. Both represent simultaneous measurements of the same physical effect recorded with indepen-

TABLE III. Comparison of the γ emission from a ''blank'' irradiated while the target rested in the outbeam position with the values obtained without irradiation. Data are presented as gross counts collected in channels which span the position of the corresponding line and were normalized as detailed in the text.

$E\gamma$ (keV)	Nucleus	With irradiation counts	Baseline Counts	Baseline Norm.[a] counts	Excess (counts)
181.6	^{172}Lu	403333 (635)	514301 (717)	404189 (600)	−856 (874)
213.5/216.7	^{178}Hf GSB	358343 (599)	455428 (675)	357921 (561)	422 (821)
325.5	^{178}Hf GSB	257174 (507)	326198 (571)	256359 (467)	815 (690)
356.0	^{133}Ba	154638 (393)	197237 (444)	155009 (358)	−370 (531)

[a]Verified by the 356 keV line of ^{133}Ba.

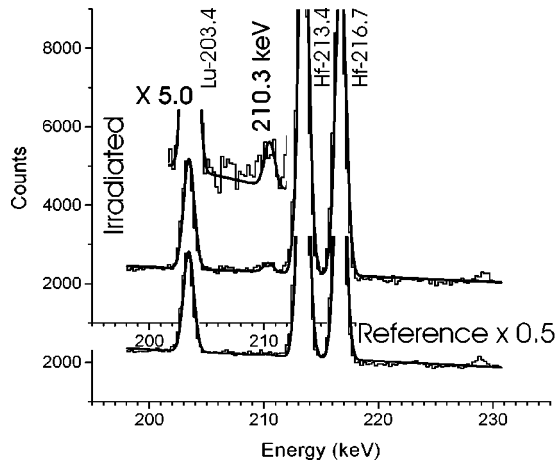

FIG. 5. Fragments of the γ-ray spectra in the region 200–230 keV accumulated during irradiation in the ''in-beam'' position (upper 2 curves), together with reference data. To facilitate comparison, the reference has been reduced by 50% while the upper curve shows the in-beam data multiplied by a factor of 5. Heavy curves plot the results of fitting Gaussian functions to the data, constrained only by a requirement for equality of linewidths over the limited range of energies shown in the figure.

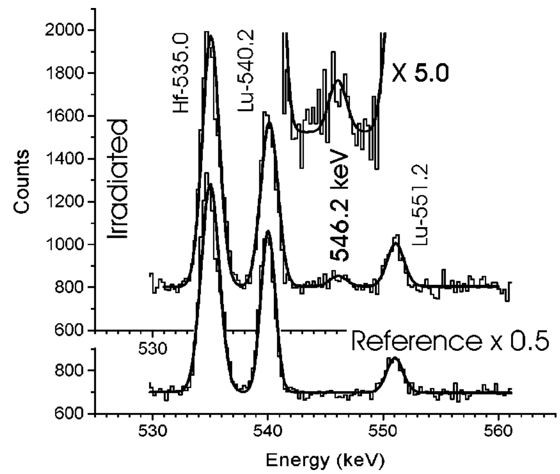

FIG. 6. The same as in Fig. 5, but for the 530–560 keV interval of the γ-ray spectra.

dent stochastic uncertainties and it can be seen that both measurements agree in the values they assign to the degree of acceleration of the spontaneous decay of the $^{178}\mathrm{Hf}^{m2}$ isomeric nuclei. For a specific example we focus further discussion upon the quantities referring to the 213.4 keV ($4^{+}\rightarrow 2^{+}$) GSB transition. In terms of standard deviations, σ the significance of the effect seen in such a single transition in one of the independent measurements is 4.9σ if statistical error is computed from the gross counts in the channels of interest. Combining the results from both platforms would give $1.61\pm 0.28\%$ to a confidence of 5.8σ.

As an alternative, if the errors are calculated from the statistics generated by separating peak ''area'' from continuum before taking the differences the statistical uncertainties in the local values of the subtracted background are included and the confidence drops to 3.9σ for each measurement. The background under the lines in this region of the spectrum is complex with structure from Compton scattering that elevates uncertainties if the background is deduced only from counts in channels near a particular line. However, if the gross counts in the channels are subtracted first, the Compton structure is removed and the entire range of channels may be used to obtain a background with statistics comparable to the fractional standard deviations of the total numbers of counts acquired in the majority of the channels. In this way the uncertainties in baseline are reduced to insignificant levels. The principal consequence is that there is confidence to 5.8σ in the conclusion that there is an enhancement of 1.6% relative to the area in the peak of the 213.4 keV component of the GSB that is caused by the x rays enhancing some member of the sum of line emission and Compton scattering which together contribute the gross counts acquired in the relevant channels. The fact that there is no comparable enhancement seen in Fig. 4 in channels which are neighbors to those containing the 213.4 keV line leads us to conclude that the observed effect is entirely due to the enhancement of the line itself with the confidence of 5.8σ. To prove that the enhancement is due to the lines by first removing the background locally, lowers the confidence to 3.9σ, however, that is still a compelling value.

From Table III it is clear that there is no comparable value of spurious enhancement found when irradiating the empty target holder with the $^{178}\mathrm{Hf}^{m2}$ isomer in the outbeam geometry. The excess counts in the 213.4 keV line are essentially zero, as can be seen as well in Fig. 3.

Further confirmation accrues from the magnitudes of the enhancements seen in other members of the GSB in Table IV and Fig. 4. It is statistically significant to conclude that the

TABLE IV. Comparison between the gamma emission from the target irradiated in the in-beam position with the values obtained between each pulse of irradiation, as detailed in the text. These data were collected with the detector system using $2K$ ADC's.

$E\gamma$ (keV)	Nucleus	With irradiation counts	Baseline Counts	Baseline Norm. counts	Excess (counts)
181.6	^{172}Lu	192583 (483)	241930 (492)	192213 (426)	370 (644)
213.5/216.7	^{178}Hf GSB	267225 (516)	333369 (577)	264862 (488)	2363 (710)[a]
325.5	^{178}Hf GSB	122568 (350)	153340 (392)	121829 (329)	739 (481)[b]

[a]Estimation of the effect: $1.27\pm 0.38\%$ of the area of the corresponding line.
[b]Estimation of the effect: $0.80\pm 0.65\%$ of the area of the corresponding line.

fractional enhancements are not the same in two members of the GSB and consequently, the decays of the ^{178}Hf^{m2} isomeric nuclei after they are triggered do not follow the path of spontaneous decay, even in the cascade through the lower members of the GSB. The larger values seen in lower members indicate that there is supplementary feeding of population into each of the lower states of the GSB from some level or levels other than the member of the GSB immediately higher in energy.

The yield of triggering events would equal the product of the number of isomeric atoms in a target, the spectral flux density from Fig. 2 at the appropriate energy, and the unknown integrated cross section $\sigma\Gamma$ for the branch of the excitation of a *K*-mixing level that ends in a state other than that of the initial isomer. Since each quantity is known except for the integrated cross section for the ''triggering branch,'' that cross section can be obtained if the transition energy is estimated. The specific value of $\sigma\Gamma$ is strongly dependent on the position of an intermediate level because of the strong variation of the x-ray flux with energy. Some information about the part of the x-ray spectrum effective for triggering can be deduced from Table II and Fig. 3. In principle a thin foil of Al serves as a high-pass filter of energies in the x-ray beam. Both calculation and direct measurement show the 50% absorption edge for a 0.7 mm thickness of Al lies at 20 keV. While the issue of triggering or not in the ''filtered'' data of Fig. 3 is not resolved statistically, it is statistically significant that the relative size of the effect is less than 50% of that of the unfiltered data shown in the top panel. In this case it can be concluded with good statistical significance that *the photon energy required to resonantly trigger the decay of the 31-yr isomer is less than 20 keV.*

Assuming the resonance band lies below 20 keV, one can deduce $\sigma\Gamma > 2.2\times10^{-22}\,\mathrm{cm}^2\,\mathrm{keV}$, if the transition to the *K*-mixing level is mediated by the bremsstrahlung component of the irradiation. There are emission lines present as well and if accidentally coincident with the energy of the trigger transition, could considerably affect the values of $\sigma\Gamma$ finally deduced. For example, the L_α emission lines of *W* are expected in the x-ray spectrum which cannot be seen on the resolution available in Fig. 2.

For the case of isomeric ^{178}Hf we have confirmed that the irradiation by x-ray photons with the energy <20 keV can induce the prompt release of the 2.446 MeV stored by the isomer into freely radiating states. This is an energy gain exceeding two orders-of-magnitude.

Further research is needed to provide greater precision to the measurements of the transition energy to the *K*-mixing level and to clarify properties of the cascade feeding the GSB. Such data will then facilitate a better understanding of these first evidences of the triggering of induced γ emission from the 31-yr isomer of ^{178}Hf with very low energy x-ray photons through large cross sections $\sigma\Gamma > 2.2\times10^{-22}$ cm^2 keV.

ACKNOWLEDGMENTS

The authors gratefully acknowledge USAF Air Force Office of Scientific Research's European Office of Aerospace Research and Development (EOARD) Contract No. F61708-98-W0027 and the U.S. Defense Threat Reduction Agency, DTRA and the USAF Air Force Office of Scientific Research, through AFOSR Contract No. F49620-99-1-0082 for support of this experiment; and the supportive efforts of our particular colleagues, students, and staff members who so generously assisted in the collection and analysis of the data.

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