SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER GCT/9601	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)* PROGRESS IN THE PRODUCTION OF SAMPLES OF GAMMA RAY LASER CANDIDATE MATERIALS		5. TYPE OF REPORT & PERIOD COVERED Final Technical 04/01/93 - 03/31/96 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Carl B. Collins		8. CONTRACT OR GRANT NUMBER(s) N00014-93-C-2091
9. PERFORMING ORGANIZATION NAME AND ADDRESS General Coherent Technology, Inc. 1216 Glen Cove Richardson, TX 75080		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS BALLISTIC MISSILE DEFENSE ORGANIZATION		12. REPORT DATE April 15, 1996 13. NUMBER OF PAGES 19
14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)* Dr. Paul Kepple Naval Research Laboratory, Code 6722 4555 Overlook Avenue, SW Washington, DC 20375 - 5000		15. SECURITY CLASS. *(of this report)* 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

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17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

19960423 000

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Gamma-ray laser materials, Isomeric materials,
Exawatt materials

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Studies of the 29 possible candidates to use as the working medium of a gamma ray laser have identified the 31-year isomer of Hafnium-178 as the best. This research was aimed at the development of a production cycle for this rare substance. A major success of this work was the discovery in byproduct debris from the synthesis of medical isotopes of a quantity of this material equal to 99% of the world's inventory. Chemical conditioning and recovery of this sample were initiated. Also, an evaluation was made of the 142 reactions with potential for restocking the existing inventories.

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I. Introduction and Significance of the Work.

I.1 Exawatt Powers

Near exawatt powers (10^{18} Watts) are encountered in concepts for directed energy beams, sterilization countermeasures against biological weapons, photothermal countermeasures against chemical weapons, full-scale nuclear simulators, and laser fusion reactors for commercially competetitive power generation. The work reported here was driven by the particular application of exawatt technology to the gamma ray laser problem but the results are equally applicable over a much wider field of potential uses. Of course, nuclear weapons can deliver powers of 0.01 to 1.0 exawatts, but they are universally considered to be unacceptable as power sources. Conversely, non-nuclear sources of exawatt powers are very difficult to conceive but could be very important to many future technologies of which the gamma ray laser is one.

Most advanced applications for extremely high powers involve the delivery of pulses with durations of picoseconds to microseconds. This means that primary energies of megajoules to gigajoules must be released, conditioned, and usually compressed to achieve the desired powers. Typical examples are found in the NOVA laser for controled fusion and in Hermes III for particle-beam applications. The great size and cost of these facilities is necessitated by the primary capacitor banks serving as the sources of the energies. Still, outputs from these devices do not yet reach the mission objectives. Scaling is particularly difficult because increases in values of stored energy invariably require further increases in physical sizes. This in turn increases the characteristic times for release of the stored energies. Delivered powers can scale with increasing size only if ever more sophisticated levels of pulse compression can be used to compensate the growing transit times. The key to the solution of these problems lies in the development of media capable of the storage of much higher levels of ***energy density***.

There is a clear need for a non-nuclear source of extremely high densities of energy storage that can be released at a controlled rate on a time scale of nanoseconds to microseconds. Many advanced applications involve delivery of the final output in the form of X rays, as in the gamma ray laser application, and there is a promising solution for those cases. X rays are the most energetic forms taken by the photons of light and there are new technologies which offer the prospect for directly multiplying the numbers and energies of X ray photons from media of even microscopic dimensions. Introduced under various names, these concepts are found in discussions of gamma-ray laser stimulation, Induced Gamma Emission (IGE), and Hot Isomer Transitions (HIT.) They all make use of the idea of releasing as electromagnetic waves the energies naturally stored in little-known isomeric materials. If scored by the energy storage divided by the transit times for energy released, these species could be rightfully termed exawatt materials.

I.2 Exawatt Materials

Any grouping of electrically charged particles can radiate electromagnetic waves. Generally the characteristic size of the distribution of the charges determines the type of photons most efficiently emitted. Antennas emit radio waves, waveguide structures emit microwaves, electrons oscillating against the positive nuclei in atoms emit light and X rays, and protons and neutrons moving in the nuclei emit gamma rays. Once emitted gamma rays are no different than X rays which often have the same energies. Since the oscillating charges in the nucleus emit their energy as short wavelength electromagnetic waves ***this process is not a nuclear reaction.*** None of the interior particles of the nucleus are emitted to cause a nuclear reaction and the nucleus finishes as the stable (non-radioactive) ground state of the same isotope of the same element.

The nucleus is the smallest part of an atom which in turn is the smallest structural unit of physical matter. Thus, quantum mechanics teaches that the motions of the charged particles found within the nucleus will represent the highest velocities of circulation possible in a sample of any material. This is a fundamental precept that means that the very highest density of (non-nuclear) energy storage will be found in the motions of those charges in nuclei. Just as in the case of atoms, in a nucleus the movement of charges can absorb photons of electromagnetic waves which in this case are X rays and make a transition to an excited state of higher energy. Because of the high energy densities and great velocities, the charges usually reradiate such energies in times too short to be measured ($<10^{-18}$ sec.) However, in rare cases quantum mechanical selection rules forbid the coupling of the particle motion to the electromagnetic field and then the high energies are stored for tens and even thousands of years in those special nuclei. Such long-lived, high energy states of excitation are termed isomeric levels and the materials are simply known as isomers. Such isomers are the natural exawatt materials.

TABLE I

List of the properties important in identifying three interesting exawatt isomers.

ISOMER	ENERGY DENSITY	SHELF HALFLIFE	TRIGGER PHOTON
	(Joules/μg)		(MeV)
Hafnium-178	**1300**	**31 years**	**<0.5**
Hafnium-179	**600**	**25 days**	**~1.5**
Tantalum-180	**40**	**10^{15} years**	**~2.5**

Research on the gamma-ray laser has identified 29 outstanding examples of isomers which score as exawatt materials. Three interesting examples are cited in Table I, but to appreciate the energy densities presented there it should be recalled that a μg of material is comparable to the amount of ink used to print one of the bold periods in the major headings of this document. It can be seen that the energy storage of the best of the isomers is more than a gigajoule per gram and since one of the key transitions for output after triggering has a lifetime of 70 nsec, the score for that material is (1.3×10^9 J / 7×10^{-8} sec) about ***0.05 exawatt per gram.***

I.3 Triggering of Exawatt Materials

Since isomers derive their long shelf lives from their poor coupling to electromagnetic waves, it was traditionally thought to be impossible to trigger the release of the stored energy. However, a recent and major breakthrough in research on the pumping of a gamma-ray laser showed the existance of a giant pumping resonance at energies around 2.5 MeV in nuclei with masses around 180. In effect it provided a gateway state through which the selection rules making an isomer long-lived could be broken. If an isomeric level initially stored an energy of 0.5 MeV only 2.0 Mev would be needed to reach such a gateway at 2.5 MeV. The absorption of an X-ray photon of that energy would excite the system to the level at which selection rules were violated and the isomer would suddenly be very strongly coupled to the electromagnetic fields. Being no longer isomeric, the sum of its stored energy and that of the trigger X ray photon would be promptly dumped as gamma rays.

The concept for dumping the energy from controlled fractions of populations of isomers has been validated in a series of experiments with the third of the exawatt materials listed in Table I. First done in the Center for Quantum Electronics at our neighbering University of Texas at Dallas (UTD) it was subsequently confirmed in separate experiments in Germany at the Technische Hochschule Darmstadt. The systematics for the occurrence of the giant pumping resonances has been proven in a series of UTD experiments which has located them in near-neighbor nuclei in the region of masses between 167 and 195.

The triggered release of energy into electromagnetic waves works and works well. The pervasive problem has been that of the 29 promising materials, only two have yet been available for study. The production of this type of ultrahigh energy density materials is still in its infancy, although our General Coherent Technology, (GCT) Inc. is beginning to emerge with a leading role in the development of fabrication techniques as anticipated in the Statement of Work for this contract.

I.4 Critical Problems

The same poor level of coupling of isomeric levels to the electromagnetic fields that give exawatt materials their attractive shelf lives makes it very difficult to produce them. Cross sections for neutron capture by potential parent isotopes in a nuclear reactor are only microbarns, a value so small as to preclude the manufacture of exawatt materials as byproducts of nuclear power. Exotic and poorly characterized production cycles were driven by available accelerators using prescriptions developed for medical radioisotopes that are far from optimized.

At the beginning of this contract work only two processes, spallation and (α,2n) reactions, had been demonstrated and both clearly illustrated the need for extensive additional research and optimization. Originally, our company, GCT, Inc. had depended exclusively upon the (α,2n) reaction using accelerator time purchased from the FLEROV facility in Russia because the cost was attractive, the yield was cleaner, and less time was required to age out undesirable radioactive byproducts. However, the spallation procedure gives about 100 times the throughput, although it has not been used in the last decade due to an appalling generation of unnecessary radioactive byproducts in the final yield of exawatt material. Samples produced by spallation seem to require about a decade to "cool" before they can be processed to remove the undesirable debris.

The significance of the problem posed by these considerations was that while the technology for the compact generation of extremely high powers seemed to have been nearly proven, the fuel cycle upon which utilization will ultimately depend had to be described as hostile technology. The clear need for the research conducted under this contract was the requirement for a cost-effective fuel cycle for the production of exawatt materials that is compatable with anticipated demand, the availability of systhesis facilities, and the acceptable levels of troublesome byproducts that are accidentally produced.

II. Technical Objectives

The research and development undertaken in this work was designed to determine, validate, and demonstrate the way to make test samples of the exawatt materials which could serve as the candidate isomers needed for use in a gamma ray laser. The means for obtaining and refining samples of high priority isotopes was to be determined. When obtained, samples were to be diluted to working concentrations in a high quality protective film such as diamond in a way to insure the laser-like properties of the nuclear lines while maintaining the physical properties and durabilities needed for pumping.

Efforts were focused upon the best candidate isomer, $^{178}\mathrm{Hf}^{m2}$ with the intent to determine how to produce, refine, dilute, and encapsulate this substance for use. Since practical quantities of this material had never been produced and processed in the United States before this work, all aspects of the problem were new. The overall technical objectives were to prove all steps in the production of finished test quantities suitable for use in the gamma ray laser project. However, to reduce risk and cost some component steps were done with simulated isotopes of less cost.

The specific objective of the work being reported here was the development of a realistic model for the production of the best of the exawatt materials, the 31-year isomer of hafnium-178 based upon the new data being obtained.

III. Summary of Technical Results

Although the details will vary, all conceivable reaction sequences do share a common set of operational concerns that regulate the conversion from feedstock to the isomer ^{178}Hf. These can be summarized in terms of six basic steps: Feedstock purification, Irradiation, Aging, Chemical separation, Isotopic separation, and Packaging. However, each step has the possibility for a multiplicity of alternative implementations that required analysis and modeling in order to assign cost/benefit ratios. The accomplishment of that task was achieved for the only known means for production of the 31-year isomer of hafnium, ^{178}Hf^{m2} , the (α,2n) reaction and the spallation procedure, as detailed in the First Annual Technical Report[1].

Both of those demonstrated fuel cycles challenge strategies for the production of the amounts of this unique material that might be needed by end-users. The nuclear reaction ^{176}Yb(α,2n)^{178}Hf^{m2} is clean but slow, while the more robust spallation process needs considerable optimization to suppress the collateral production of undesirable byproducts. There is a very clear need for a "magic bullet" in the form of a reaction for the production of commercial amounts of the hafnium isomer at reasonable scales of investment without the generation of noxious byproducts that are hazardous to remove and difficult to destroy.

The second major accomplishment under this contract was the preparation of a definitive survey of all nuclear reactions capable of producing the ^{178}Hf^{m2} so that they could be subsequently screened according to practical criteria. The results of that study were reported in the Second Annual Technical Report[2]. As detailed there, 142 nuclear reactions for the production of ^{178}Hf^{m2} were analyzed in terms of their economies of angular momenta and energies. The desired product, ^{178}Hf^{m2} is distinguished by an unusually large spin of 16$\hbar$ and a relatively high internal energy. While the energy can be obtained from favorably chosen mass defects, the problem of producing a high angular momentum in the product is very difficult.

Basically, a nuclear reaction is a collision in which a projectile hits a target. In the absence of either extraordinary impact parameters for such reactive collisions or massive projectiles, the incident particles must arrive with very large velocities or the targets must already have large spin angular momenta. If massive projectiles are selected, acceleration is difficult; high velocities of incidence imply large kinetic energies that may open many unwanted competing channels for output; and high spin targets are usually comprised of rare isotopes or other spin isomers that are just as hard to fabricate. There were no "magic bullets" discovered but closure was obtained[2].

The detailed analysis was quite complex and since it has been fully reported earlier[2] a complete repetition is not warranted in this summary. However, in view of the most recent developments a limited review is important. Systematics show that in the region of nuclear charge number corresponding to hafnium cross sections are reduced by about an order of magnitude for each free charged particle emerging among the products. This suggests that the merits of reactions be arranged in order of the total atomic number in the input channel, $Z_T = Z_i + Z_t$, where the subscripts denote the total charge, the charge of the projectile, and the charge of the target nucleus, respectively. Reactions for which $Z_T = 72$ would require the emission of no charged particle to produce $^{178}Hf^{m2}$ because Hf has $Z = 72$, and so would offer the potential for maximal cross sections if it could be also arranged to produce a total spin of 16$\hbar$ or greater. The reactions for $Z_T = 72$ are summarized in Table II reproduced from the Second Annual Technical Report[2]. While understanding of the selection criteria reported in some columns requires reference to the full report, it is immediately clear why the Dubna reaction is favored by a target of practical abundance, different chemistry from the product, a reasonable projectile energy, and a total reaction channel spin of the order of 21$\hbar$.

Overlooked at the time of the report was the nuclear reaction $^{179}Hf(n,2n)^{178}Hf^{m2}$ because it required high energy neutrons, precluded chemical isolation of the product from the target because both were Hf, and because our scaling estimates of the effect of insufficient channel spin of 11$\hbar$ relegated it to the decade of cross section values one decade lower than the Dubna reaction. As described below, since the time of that report we have learned that this mode of production has been favored by the new Kansai Advanced Photon Research Institute of Japan. Nevertheless, it seems a borderline case which is rendered attractive only by the accidental coincidence of the required projectile energy and the energy characteristic of fusion neutrons. Since there are plans at Kansai to construct a very large fusion neutron source, the utility of this reaction in Japan may prove greater than the estimate made at the time of the Second Report[2], but the overall fuel cycle based upon this reaction will still need a very expensive and challenging level of isotopic separation of the target to extract the ppm concentrations of the mass-178 Hf from the mass-179 target Hf.

During the final year of the contract research a considerable contraction of funding limited activities. Our Senior Research Scientist, C. B. Collins with support from NATO organized the First International Gamma Ray Laser Workshop in Romania, a location encouraging the participation of scientists from Eastern-bloc countries. A copy of the announcement of the workshop and summary of the Proceedings is found in Appendix II. It was on this occasion that the Kansai approach was first described. Proponents revealed that because of the availability of a fully operational laser isotope separation facility, the unprecedented level of isomer separation was being planned to become operational in 1999. Joining it to a greatly upgraded fusion neutron source, Kansai was projecting throughput of a complete fuel cycle for the production of $^{178}Hf^{m2}$ at 1gram/year.

Notwithstanding the Kansai effort, it still seems clear to about 90% confidence, that spallation offers the best approach. The small uncertainty arises because a few obscure and exotic reactions warrant further consideration, but it is unlikely they will be proven effective. ***It is reasonable to conclude that spallation will be the US fuel cycle of choice and efforts to optimize that system should begin.***

Because all conceptually viable fuel cycles require substantial investment, it would be wise to demonstrating that the favorable triggering of the $^{180}Ta^{m}$ isomer could actually be accomplished in the case of the $^{178}Hf^{m2}$. Such a step of risk reduction would require some sample of the material be obtained for preliminary testing. At the present time the only actual source of $^{178}Hf^{m2}$ is Dubna in Russia which makes about 4 × 10^{14} nuclei per year, a very small amount.

As detailed in last year's report[2], we discovered that a unique spallation experiment conducted in 1980 at Los Alamos National Laboratory (LASL), while aiming for medical isotopes had incidentally produced[3] an amount of $^{178}Hf^{m2}$ estimated by us to be about 100 years' production from Dubna. Inhibited by a great amount of radioactive debris, the utility of the irradiated target was originally considered to be remote and over the intervening years it was lost from the inventory. Unappreciated was the fact that by 1995 the hazardous byproducts had "aged out" because of their faster decay rates.

In 1994 we succeeded in locating the spallation target and were instrumental in returning it to the inventory as LASL Target #29-3-1. The original spallation experiment had been described[3] as the irradiation of 1 kg of natural Ta by the 800 MeV proton beam from the Los Alamos Meson Physics Facility (LAMPF) for four months during which the target accumulated an integrated exposure of 0.5 to 1.0 Ampere-hour. That Target, #29-3-1 consists of three plates of Ta of about 250 g each containing a concentration of Hf of about 10^{-9}. The remaining 250 g has been located in the form of HDEHP residue which is not conducive to further processing to extract such a small Hf fraction. In any case accountability now exists for all of the original 1980 spallation target.

As described in last year's report[2], we obtained an assay of the Target #29-3-1 consistent with the initial estimate of somewhat over 10^{17} nuclei. The initial population had decayed by about one half of a halflife and Target #29-3-1 represents 75% of the mass originally subjected to the spallation reactions. The data corresponded to 4.5 × 10^{16} isomers of $^{178}Hf^{m2}$. The activity of the isomeric content is only 0.87 mCi while the activity of the Hf fraction is 20 mCi. Integrated together the noise from other species is a dangerous 100 Ci.

To be useful for the pumping experiments necessary to prove feasibility of dumping the stored energy, the dangerous level of background radioactivity must be removed. Since the fraction which is chemically Hf has an activity of only 20 mCi, chemical separation of the Hf parts from the unreacted Ta is an attractive but difficult option. The sole source of the service needed was determined to be LASL and they were contracted to extract the entire Hf fraction from Target #29-3-1. The hazards involved necessitated their upgrading of the handling facility and that is introducing delay in the completion of the task. It is the intention of General Coherent Technology, Inc. to complete the chemical separation with support from corporate resources.

IV. Technical Postscript

After completion of the subject contract, the scientists of the GCT, Inc. were invited to participate at the expense of the Company in a first proof-of-principle for the triggering of an actual sample of the $^{178}Hf^{m2}$ isomer. Using 2 × 10^{13} of the Dubna isomers at a surface concentration of 5 × 10^{14} /cm^2 on 25μg/cm^2 of C-foil a test for triggering was conducted with the Tandem accelerator at Orsay in France. Alpha particles were used for triggering. The start pulses for the collection of data were derived from the detection of backscattered α's. For each event, the energy loss of the scattered α was recorded together with the outputs (if any) from 74 crystal detectors arranged in a 4π geometry around the target.

The target was only 4-5% concentrated in isomers and so the dominant signal was expected to be the excitation of the yrast band from the ground state which would give an order of photon coincidence from the gamma detectors that was loosely proportional to the energy loss. Because of the mass of the α's it was expected that some angular momentum could be imparted to the ground states in collision but that more energy would have to be transferred to excite to a higher member of the rotational (yrast) band accessible from the ground. The excited state would decay with the simultaneous emission of photons in a cascade in which each component transition carried away 1 or $2\hbar$. Some of the photons would be detected in coincidence from the surrounding detectors. The signature of such events would be the correlation of a moderate order of coincidence, 1 to 3 or 4 with the loss of substantial energy from the incident projectiles.

In contrast, the triggering of isomers was expected to produce a higher order of coincidence with lessened transfer of projectile energy since the target was starting with $16\hbar$ and the energy transfer needed to release the cascade of photons was only the trigger energy, believed to be small. Considering the amount of isomers and the beam current available, if accomplished at the cross section characteristic of "normal" unhindered events the triggering of isomers should have given a number of events at the level of hundreds. In practice we obtained millions of events, many characterized by very low energy losses from the trigger α and very high multiplicities of the coincidences of the gammas of the order of 8-$16\hbar$. Of first importance is to eliminate the possibility of contributions to the multiplicity from unknown spurious causes. Because of the extraordinary number of events matching the expected signature of isomer triggering, it will be months before even a preprint of the results can be released by this collaboration.

In summary, either an unknown type of spurious enhancement occurred in the first test of triggering, or the 31-year isomer ^{178}Hf^{m2} triggers with the large cross section already found for ^{180}Ta^{m} and at a very favorably low energy.

V . References

1. C. B. Collins, First Annual Technical Report, NRL Contract No.N00014-93-C-2091, April, 1994.

2. C. B. Collins, Second Annual Technical Report, NRL Contract No.N00014-93-C-2091, May, 1995.

3. H. A. O'Brien, "Utilization of an Intense Beam of 800 MeV Protons to Prepare Radionuclides," Nuc. Instrum. and Methods B **40/41**, 1126 (1989).

Table II

Production of (31-yr) Hf-178

Reactions having total input charge = 72

Reaction Target	Projectile	Emission	Target spin	Threshold energy (MeV)	Coulomb barrier (MeV)	Projectile energy (MeV)	Internal E of excitation (MeV)	Orbital momentum L-max	Channel spin h-bar	Abundanc %
Hf-177	n	*gamma*	3.5	-5.17	0					18.6
Hf-178	n	n	0	2.45	0	7.45	5.0	5.1	5.1	27.1
Hf-179	n	2n	4.5	8.55	0	13.5	5.0	6.9	11.4	13.7
Hf-180	n	3n	0	15.9	0	20.9	5.0	8.6	8.6	35.2
Hf-182	n	5n	0	28.3	0	33.9	5.6	11	11	U
Lu-177m	p	*gamma*	11.5	-5.85	11.8	16.8	22.7	7.7	19.2	U
Lu-176	d	*gamma*	7	-9.73	11.4	16.4	26.1	11.2	18.2	2.61
Lu-176	t	n	7	-3.48	11.1	16.1	19.6	13.9	20.9	2.61
Lu-175	t	*gamma*	3.5	-9.77	11.1	16.1	25.9	13.9	17.4	97.3
Yb-176	*alpha*	2n	0	17.2	21.5	26.5	9.3	21	21	12.6
Yb-176	He-3	n	0	-3.35	22	27	30.4	18	18	12.6
Yb-174	*alpha*	*gamma*	0	4.54	21.6	26.6	22.1	21	21	31.6
Er-170	Be-9	n	0	6.85	39.5	44.4	37.6	43.4	43.4	14.9
Gd-160	O-18	*gamma*	0	18.7	70.4	75.4	56.7	84.5	84.5	21.8
Te-130	Ca-48	*gamma*	0	81.5	132.4	137.4	55.9	201.3	201.3	34.5

Kansai Reaction
Dubna Reaction

Appendix I

Index of Technical Reports
from
NRL Contract N00014-93-C-2091

I. First Annual Technical Report, GCT/9401covering the period:4/01/93 - 3/31/94, April, 1994

II. Second Annual Technical Report, GCT/9501covering the period:4/01/94 - 3/31/95, April, 1994

Appendix II

Announcement and Summary of the First International Gamma Ray Laser Workshop

Organizing Committee

C. B. Collins	*University of Texas at Dallas, USA*
R. Coussement	*Katholieke Universiteit Leuven, BELGIUM*
G. R. Hoy	*Old Dominion University, USA*
Yu. Ts. Oganessian	*JINR, Dubna, RUSSIA*
L. A. Rivlin	*MIREA, Moscow, RUSSIA*
A. Sandulescu	*Romanian Academy, ROMANIA*
V. I. Zoran	*Institute of Physics and Nuclear Engineering, ROMANIA*

Program Co-Chairs

J. J. Carroll	*University of Texas at Dallas, USA*
A. A. Zadernovsky	*MIREA, Moscow, RUSSIA*

Romanian Organizing Committee

Institute of Physics and Nuclear Engineering
Bucharest, ROMANIA

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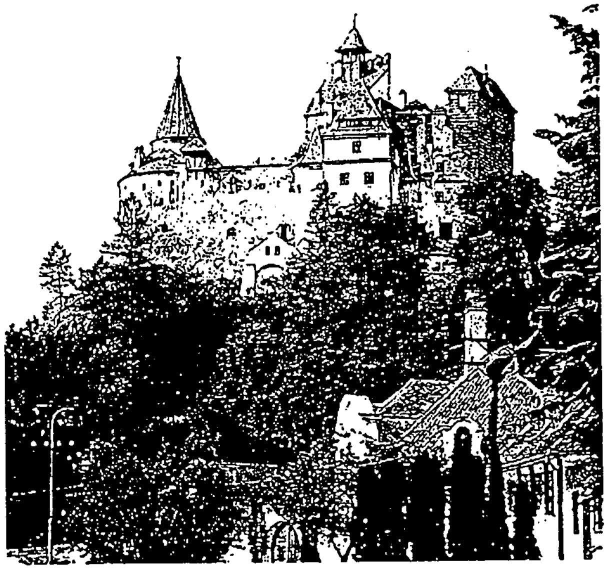
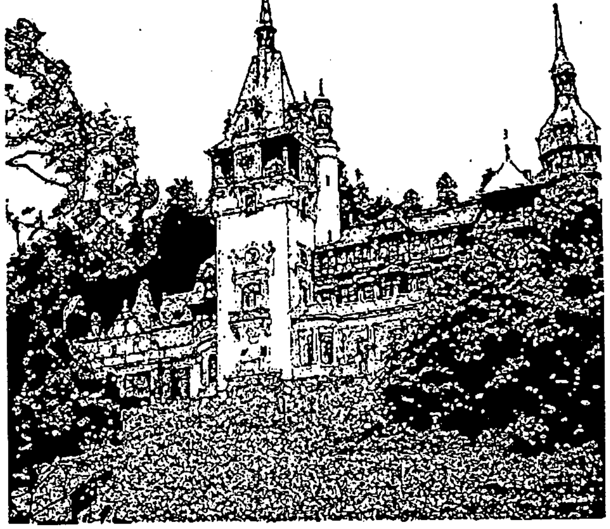


Nearby Castle of Count Vlad Tepes (Dracula)

Final Announcement

First International Gamma-Ray Laser Workshop Predeal '95



Nearby Peles Castle

August 19 - 23, 1995
Predeal, Romania

A satellite of the Hyperfine Interactions Conference at the Katholieke Universiteit, Leuven, Belgium

Organized under the auspices of:
The Romanian Academy
The Ministry of Research and Technology of Romania
The Institute of Atomic Physics of Romania

Predeal '95

It is a great pleasure to announce that the program of the **Gamma-Ray Laser Workshop - Predeal '95** is completely full. Because of this, it is of considerable importance to determine a best estimate of actual attendance. Your return of the enclosed registration form is urgently requested.

As originally announced, the Workshop will be held from August 19 to 23. The timing was set to facilitate the use of the lowest fares which were supposed to require a Saturday night stay at the destination, meaning that arrivals are expected on the 19th (Saturday,) with the first night of accommodations being that Saturday night. Sunday, 20th is the "Conference Trip" which is intended to provide the opportunity for us all to get acquainted or reacquainted while seeing some of the unique scenery in the neighborhood. Technical sessions are full and begin on Monday morning and finish Wednesday afternoon, the 23rd. Accommodations for the night of the 23rd can be arranged for either the conference site, or Bucharest, if requested on the Registration Form.

Archival Proceedings

In additional to the Technical Digest to be distributed at the registration there will be the opportunity to submit manuscripts for a bound volume of the Hyperfine Interactions Journal dedicated to the topic of our Workshop that can serve as a reference source for the future development of our emerging field. L. A. Rivlin and C. B. Collins will serve as Guest Editors of **The Proceedings Volume** and will collect material from: 1) the reviews of the Workshop and 2) the manuscripts of the Special Issue of *The International Journal of Laser Physics*. If you wish to have your work considered for inclusion in The Proceedings Volume, you must submit before, or at the latest bring to, the Workshop **two copies** of a complete manuscript **with original figures.**

Archival Proceedings

Since the Workshop follows so closely in time the collection of manuscripts to the previous "Special Issue," the editors would welcome resubmission of the same material by the original authors **if it has been updated or revised** to reflect the progress in understanding which characterizes such a rapidly developing field as ours. However, manuscripts submitted for The Proceedings Volume should identify whether they are revisions from the earlier "Special Issue" or new papers prepared for the Workshop. Essentially the same material should not be submitted both ways.

The Deadline for receipt of manuscripts for The Proceedings Volume is the Opening Session of the Workshop.

Review of Papers

Manuscripts will be reviewed during the Workshop and be returned to the authors by the second day. It is very important that revisions then be completed before adjournment, in all cases practicable. There will be no publication charges.

General Information

Along the wooded valley cut into the Carpathian Alps by the Prahova river lie several attractive towns which are characterized by different traditions, such as mountain sports, conference centers, and resorts. Because of a sequence of NATO Advanced Study Institutes held there, the better known is Predeal, the name by which all have become [mis]identified. Originally scheduled for the village of Timis our "Predeal '95" has been invited by the Romanian Academy to their even more attractive facility at another Prahova town, Sinaia, known for the royal summer residence, Peles, the castle shown in the figure.

Arrival

There are now several international airports in Romania and if arriving by air it is essential to arrange your flight to Bucharest (Otopeni). Reception and accommodations will be handled by Welcome Tours, a professional conference management agency. It is their intention to meet all participants when they emerge from the customs area. However, it will be necessary for you to notify them of the details of your arrival on the Registration Form, as soon as possible. Because of the popularity of the Romanian Black Sea Coast in August, crowds at the airport are heavy. Early information will help us greatly to insure that no one is inadvertently carried astray by the seaside crowd.

Costs

Conference fees will be $50 US for registration, $46 US single and $57 US double per day for accommodations, and $20 US per day for meals. Participants who are co-authors of accepted abstracts may be eligible for reduced rates and will be contacted by the Program Co-Chairs. The bound Proceedings Volume can be ordered for $75 US at the registration.

Please note: Payment of the conference fees will be expected in hard currency or may be charged to major credit cards (American Express is preferred).

Looking forward to seeing you at Predeal '95

Proceedings
of the
First International Gamma-Ray Laser Workshop
GARALAS '95

A NATO - Advanced Research Workshop
held
August 19 - 23, 1995
Predeal, Romania

FORWARD

The development of a gamma-ray laser has stood as a formidable challenge to science and scientists for more than thirty years. In that time visible lasers have become commonplace in everyday life, appearing in science, surgery, supermarket and, through the compact disc, sound. No less remarkable has been the march toward ever increasing photon energies, now reaching soft X rays. Still, the ultimate goal of the coherent production of gamma rays remains unfulfilled, despite the recognitinon of its promise so early after the invention of the ruby laser. The strongly interdisciplinary nature of the problem requires a fusion of concepts from traditionally unrelated fields like quantum electronics and nuclear physics and this has provided both the challenge and the attraction. From this intriguing combination it is understandable that for many the gamma-ray laser has become more than just a topic of research, but instead of life-long goal.

In this context, the present defines a unique point in time which may prove to be a milestone in gamma-ray laser research. Recently introduced concepts and experimental results are extremely encouraging and these developments have arrived at a moment of great opportunities. Now, it has become possible to convene a meeting of truly international scope by which to assemble the leading scientists and to crystallize their community in to a recognizable field, perhaps as some have suggested into an "invisible laboratory". This First International Gamma-Ray Laser Workshop **GARALAS '95** is intended to provide a fertile environment for the exchange and critical review of ideas and results. Although some concepts may be controversial, we are reminded of the importance of open discussion in a collegial atmosphere: "It is better to debate a question without settling it than to settle a question without debating it" [Joseph Joubert].

As Co-Chairs we have been charged with organizing the Program of the Workshop so as to encompass the widest possible range of topics, both experimental and theoretical, and to include the leading scientists from around the world. It has been a great pleasure to accept this challenge and we thank the members of the International Organizing Committee, Profs. C.B. Collins, R. Coussement, G.R. Hoy, Yu.Ts. Oganessian, L.A. Rivlin, A. Sandulescu and V.I. Zoran, for this opportunity. We hope to have discharged our responsibilities successfully and look forward to the future with great anticipation.

James J. Carroll	*University of Texas at Dallas/Youngstown State University*
Anatoly A. Zadernovsky	*Moscow Institute of Radioengineering, Electronics and Automation*

Program Co-Chairs
GARALAS '95

PREFACE

The movement of charged particles in confined volumes leads to the emission of electromagnetic radiation. Electrons in antennas emit radio waves and microwaves; electrons moving in molecules and atoms radiate photons of infrared, light, or x-rays; and charges moving in nuclei emit gamma rays. At small scales the motions of charges are quantized and such electromagnetic radiations are emitted during transitions between the discrete levels of energy storage that are allowed in the confined volumes. However, in some cases because of selection rules, this quantized energy storage can last for relatively long times, of milliseconds for "metastable" atoms and years for "isomeric" nuclei. The case of isomeric nuclei represents the greatest concentration of electromagnetic energy that is possible without a nuclear reaction. Storage densities reach megaJoules/milligram for durations of a third of a century.

The same rules of electromagnetic radiation apply to all systems, so in principle, excited states of nuclei and even isomers could be induced to emit their stored energy in a concentrated flash of short wavelengths. There is some coherence in all stimulated emission and an ultimate goal of research in this direction has been to develop enough coherence to realize a gamma-ray laser, the term which common usage has affixed as a name to the entire field. However, success in even the earliest stages of Induced Gamma Emission (IGE) would have great technical significance.

A particularly interdisciplinary problem, induced gamma emission (IGE) depends upon concepts which must be fused from traditionally diverse fields such as quantum electronics, nuclear physics, and materials science. Both strength and weakness at the same time, such richness in diversity had made it difficult to crystallize a truly recognizable field. However, recent advances in research have had aspects of breakthroughs and the time had clearly arrived to provide the structure for the responsible investigation and development of Induced Gamma Emission (IGE) under proper international auspices. The NATO-Advanced Research Workshop, "GARALAS '95" was the first meeting of researchers from such diverse backgrounds and communities to span the entire scope of issues needed for an examination of the feasibility of a gamma-ray laser and other IGE devices.

The First International Gamma-Ray Laser Workshop, GARALAS '95, was organized under the auspices of an International Advisory Board:

Prof. Carl B. Collins, Director, Center for Quantum Electronics, Univ. of Texas at Dallas, TX, USA
Prof. Romain Coussement, Inst. voor Kern-en Stralingsfysika, Kath. Univ. Leuven, Leuven, Belgium
Prof. Gilbert R. Hoy, Phys. Dept., Old Dominion Univ., Norfolk, VA, USA
Prof. Yuri Ts. Oganessian, Director, Flerov Lab. of Nuclear Reactions, JINR, Dubna, Russia
Prof. Lev A. Rivlin, Moscow Inst. of Radioengineering, Electronics, and Automation, Moscow, Russia
Prof. Aurel Sandulescu, Vice-President, Romanian Academy, Bucharest, Romania
Dr. Valeriu T. Zoran, Director, Inst. of Phys. and Nuclear Engineering, Bucharest, Romania,

with Drs. Collins and Zoran serving as Workshop Directors. The scientific program was organized by the Program Co-Chairs, Prof. James J. Carroll, Dept. of Phys., Youngstown State Univ., Youngstown OH, USA and Dr. Anatoly A. Zadernovsky, Moscow Inst. of Radioengineering, Electronics, and Automation, Moscow, Russia.

The Workshop GARALAS '95 was centrally located in an attractive region of Romania in order to build upon a strong scientific infrastructure while balancing travel costs and accessibility. Objectives were to promote the exchange of ideas and results while obtaining critical review of our work within the normal and pleasant framework of invited and contributed talks.

Hosted by a Romanian Advisory Board Chaired by Dr. T. Necsoiu, Director, Institute of Atomic Physics of Romania, the Committee of Dr. D. Barb, Acad. I. I. Popescu, Dr. M. Petrascu, and Acad. V. Vlad assisted by the Scientific Secretaries, D. L. Penache and C. A. Ur, situated GARALAS '95 at the Timis conference center in the Carpathian Alps of Romania. Near the town of Predeal, it was located in a wooded area at a modest altitude and provided a beautiful venue for the 46 registered participants. As originally announced, the Workshop was held from August 19 to 23, 1995. Sunday, 20th was the "Conference Trip" which provided the opportunity for participants to get acquainted or reacquainted while enjoying some of the unique scenery in the neighborhood, including the castle of the Count Vlad Tepes (Dracula.) The excursion finished with a trip to the Carpathian overlook Fundata (which means "End of the World") and a grill in the hidden valley village of Moieciu. Technical sessions were full and began on Monday morning and finished Wednesday evening, the 23rd.

Substantial progress was reported at GARALAS '95 in all of the critical issues. Particular experiments with the isomer Ta-180 had shown that intense flashes of x rays can trigger IGE from isomers without nuclear reactions - and without particle emissions or lingering radioactivities. Cross sections were the largest ever found for x-rays interacting with nuclei at these energies where nuclear reactions do not occur, and exceeded theoretical estimates by six orders-of-magnitude. Systematic studies of the experimental data predicted that similar cross sections would be found for the isomers of Hf-178, storing the greatest known amounts of electromagnetic energy. There was significant controversy over the energy needed for the trigger photon to release the storage in Hf-178 with predictions ranging from 13 to 300 keV.

Theoretical results suggested that the development of some coherence during superradiant IGE could permit the manipulation of the phasing (directionality) of outputs without optics or mirrors. Gain-without-inversion (GWI) techniques were described that could give control of coherence well below threshold for conventional lasing and AVL*I*S Atomic Vapor Laser *Isomer* Separation methods could provide for the concentration of isomeric nuclei to solid densities for use in future experiments and prototype devices. Controversial but impressive experimental results indicated that collective interactions of excited nuclei had already led to the self stimulation of gamma-ray output and the coherent fractions of output from assemblies of nuclei such as Te-125 were reported to exceed 1%. Such exciting results had not been generally appreciated before the Workshop because of their interdisciplinary nature and clearly proved the importance of continued research on these topics. The frontiers of our vision were extended greatly by advanced proposals for stimulated annihilation radiation, gamma emission from deeply cooled beams, and for even an entirely new field of quantum nucleonics, the analog of quantum electronics.

There were profound consequences of the technical accomplishments of this First International Gamma-Ray Laser Workshop, GARALAS '95. Particular concern was focused by one US participant, Dr. H. Roberts whose report is included in this volume when he advised: "... achieving stimulated gamma release without a fission process, is a worthy goal. Such an accomplishment would *likely be comparable to the initial nuclear breakthrough over 50 years ago.*" This realization had the effect of firming the impression that the time had arrived to provide the structure for the responsible investigation and development of Induced Gamma Emission (IGE) under proper international auspices. Accordingly, the GARALAS '95 Community elected to reorganize into a permanent commission, ICIGE, the International Commission on Induced Gamma Emission. It is an open organization whose Constitution was adopted after the Workshop on September 8, 1995. The Commission has an Advisory Board, a Secretariat (Contact person, C. B. Collins), an Administrative Center in Bucharest, Romania, as well as editorial offices in Youngstown, USA and Moscow, Russia.

The First International Gamma-Ray Laser Workshop, GARALAS '95 was completely successful in crystallizing a community of colleagues in this new interdisciplinary field of IGE, but also went beyond the accomplishments of the technical program to build a structure to encourage further responsible interaction. The pervasive conclusion was that the way seems clear for rapid and significant future progress.

The Guest Editors would like to take the opportunity to express the great appreciation of the GARALAS Community to the sponsors of the First International Gamma-Ray Laser Workshop organized as a NATO Advanced Research Workshop (ARW):

- NATO Scientific and Environmental Division

US Air Force European Office of Aerospace Research and Development (EOARD)
Katholieke Universiteit Leuven, Institute for Nuclear and Radiation Physics
SRS Technologies, Inc. (US)
University of Texas at Dallas, Center for Quantum Electronics
Romanian Academy
The ELIAS Foundation of Bucharest, Romania
The Ministry of Research and Technology of Romania
The Institute of Atomic Physics, Bucharest, Romania
The Institute of Physics and Nuclear Engineering, Bucharest, Romania
The Institute of Optoelectronics, Bucharest, Romania

Their support and encouragement were responsible for the successes of GARALAS '95.

Carl B. Collins
Dallas, Texas USA

Lev A. Rivlin
Moscow, Russia