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14. ABSTRACT

This report results from a contract tasking Institute of Physics Academy of Science as follows: 1/ Experimental investigation of kinetics of atomic iodine generation via F atoms based on the chemical reaction of F2 with NO, and a sequential reaction of F with HI performed on a small-scale device will provide detailed information about feasibility and efficiency of this method for a COIL.

2/ Experimental investigations of the small signal gain distribution and laser generation on the supersonic COIL device modified for injections of gaseous reactants will provide detailed results on the most efficient and advantageous location of atomic iodine injection into the singlet oxygen flow in the laser.

3/ More sophisticated computational CFD model of this reaction system will be developed to optimizing the mixing conditions and interpret experimental results.

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STATEMENT

- (1) **The Contractor, Institute of Physics of the Academy of Sciences, hereby declares that, to the best of its knowledge and believes, the technical data delivered herewith under Contract No. FA8655-05-M4027 is complete, accurate, and complies with all requirements of the contract.**

- (2) **I certify that there were no subject inventions to declare as defined in FAR 52.227-13, during the performance of the Contract No. FA8655-05-M4027.**

Name and Title of Contractor:

Dr. Jarmila Kodymová

CONTENT

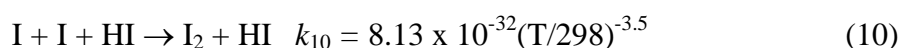
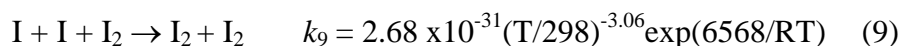
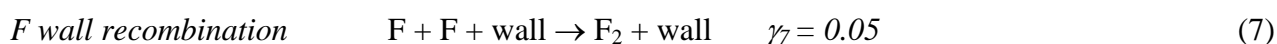
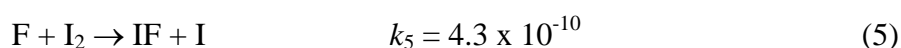
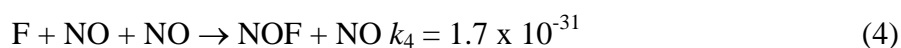
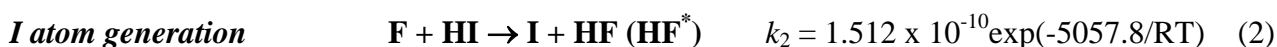
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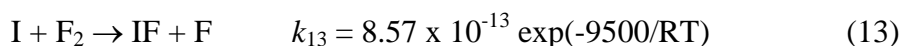
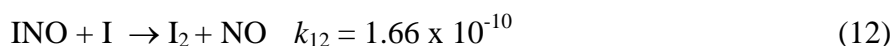
Outline of planned grant tasks

- Experimental investigation of kinetics of atomic iodine generation via F atoms based on the chemical reaction of F₂ with NO, and a sequential reaction of F with HI, performed on a small-scale device, providing detailed information about feasibility and efficiency of this reaction system.
- Experimental investigation of small signal gain and laser generation on the supersonic COIL device modified for injections of gaseous reactants, providing detailed results on the most efficient and advantageous location of atomic iodine injection.
- Elaboration of more sophisticated CFD model of this reaction system, providing useful information about mixing conditions, used for experimental device designing and interpretation of experimental results.

I. Brief summary of previous investigations on the F → I reaction system

The results on investigation of atomic iodine generation via chemically generated atomic F gathered for this report follow up with the experimental and theoretical results on this reaction system that were presented in our previous EOARD reports – the interim Reports 001 [1] and 002 [2], and the Final Report [3] of the EOARD grant No. 033063. In this study, the kinetic package of reactions given below (with relevant rate constants in cm³molecule⁻¹s⁻¹ and cm⁶molecule⁻²s⁻¹, respectively) has been involved.





Reaction enthalpies, from which the heat effect of individual reactions can be estimated, are given in the EOARD report [1].

The results gathered during mathematical modeling of this reaction system and experimental studies obtained on several small-scale reactors are summarized as follows.

1. Experiments performed with 10% mixtures of reactants

- Maximum production of atomic iodine was obtained with the NO:F₂ ratio of 1:1, corresponding to the stoichiometry of reaction (1) for F atom generation.
- At the ratio NO:F₂ > 1, the rate of atomic iodine production was limited by the F₂ flow rate. At NO:F₂ ≤ 1 and simultaneously HI:F₂ < 1, the concentration of atomic iodine dropped significantly with increasing F₂ flow rate due to the reaction of I atoms with F₂ (13). This effect weakened with higher HI flow rate due to an additional generation of I atoms in the reaction of HI and F atoms formed in this reaction.
- At the ratio NO:F₂ < 1, the rate of atomic iodine production was limited by NO flow rate, while at NO:F₂ > 1, the atomic F (and consequently atomic I) generation was affected only slightly by NO flow rate due to a weak effect of loss-reactions (3) and (4).
- The rate of atomic I production grows with increasing HI flow rate at HI:F₂ < 1 and HI:NO < 1. This agrees with the kinetics of reaction (2) in the case of the HI flow rate lower than the rate of F atoms production (“titration” of F atoms with HI). A significant excess of HI (vs. NO and F₂) in the region of low pressure (1.5 – 2.5 kPa (11 – 19 torr)) did not reduce the production rate of I atoms (a low effect of loss-reaction (10)). At higher pressures (above 8 kPa (60 torr)), the HI excess (together with N₂ in HI/N₂ mixture) reduced the I production obviously due to the acceleration of ternary loss-reactions (3), (6), (8), (10) and (11).
- Production of atomic I was significantly affected by a sequence of secondary gases (NO and HI) admixing into the primary F₂ flow. A higher rate of I production was obtained with the HI – NO injection sequence (called further HI–NO injection order), which obviously caused

a more uniform pre-mixing of HI before its reaction with F atoms (2), and suppressed the F atom loss in the reactions with NO (3), (4).

- The time interval between F₂+NO mixing and HI admixing might be prolonged up to 1 ms without a significant decrease in the I production (at pressures up to 9 kPa (67 torr)). This proved a rather long lifetime of F atoms.
- Temperature of the reaction mixture was up to 700 K. It was influenced mainly by the F₂ flow rate due to the exothermic reactions F₂+NO and F₂+I. An excessive NO and/or HI flows (mixed with N₂) caused a slight decrease in the temperature due to diluting effect of nitrogen.
- The highest rate of atomic iodine production was 180 μmol/s, and the yield of atomic I ranged from 6% to 30% (related to F₂) (at HI-NO injection order). A maximum concentration of atomic iodine attained in this system was $8 \times 10^{15} \text{ cm}^{-3}$ at the total pressure of 9 kPa (67 torr) and within a time interval from 0.45 to 2 ms after admixing the last reactant. With the NO-HI injection order and pressure of 8 kPa (60 torr), the maximum I concentration was lower ($5 \times 10^{15} \text{ cm}^{-3}$).

2. Experiments performed with 20% F₂/N₂ mixture and non-diluted NO and HI gases, NO–HI injection order

- Production of I atoms was substantially higher with more concentrated reaction gases. The production rate was nearly directly proportional to the flow rates of reactants up to a high total pressure, 17 kPa (127 torr).
- The production rate was not significantly affected by a time delay of F₂ and NO mixture in the “F reactor” up to 1.1 ms (at 8.5 kPa). Also extending the time interval between F atoms injection into the “I reactor” and HI admixing (up to ~1 ms) had no negative effect (at pressure in the I reactor of 4.2 kPa (~32 torr)). Both these experimental results agree with modeling results, confirming rather long lifetime of F atoms.
- High concentrations of atomic iodine (up to $1.6 \times 10^{16} \text{ cm}^{-3}$) were obtained in these conditions. The atomic I yield was 47% (related to F₂) or 34% (related to HI). The higher yield obtained with more concentrated reacting gases could be ascribed to a higher temperature in the reaction system, which accelerates the rate of production reactions (1) and (2), and decelerates the rate of ternary loss-reactions (3), (6), and (8)–(11). Due to a lower content of nitrogen diluent, the rates of ternary loss-reactions (3), (6), (8), and (11) are also

reduced. The gas temperature was significantly higher in these measurements (800 – 1300 K) than in the experiments with diluted reactants.

- The rate constant of reaction $F_2 + HI$ was estimated. It is $1.5 \times 10^{-14} \text{ cm}^{-3}$ at 670 K.
- Further, the rate of wall recombination of I atoms was estimated using a fine stainless steel mesh, through which the gas flew, and I atom loss on this mesh was measured. This measuring, supported by computational modeling, has shown that the wall recombination of both F atoms and I atoms is controlled by diffusion. Loss of F and I atoms by the wall recombination in the reactor and during gas injection is owing to this mechanism less than 10%.

II. New experiments on the $F \rightarrow I$ reaction system

These experiments were performed to examine the production of I atoms at pressures over 10 kPa, which could provide in a supersonic COIL sufficient penetration of the secondary gas containing I atoms into the primary flow downstream the nozzle throat.

1. Experimental

Experiments were performed on the small-scale iodine reactor with the embedded reactor for generation of F atoms (see **Fig. 1**).

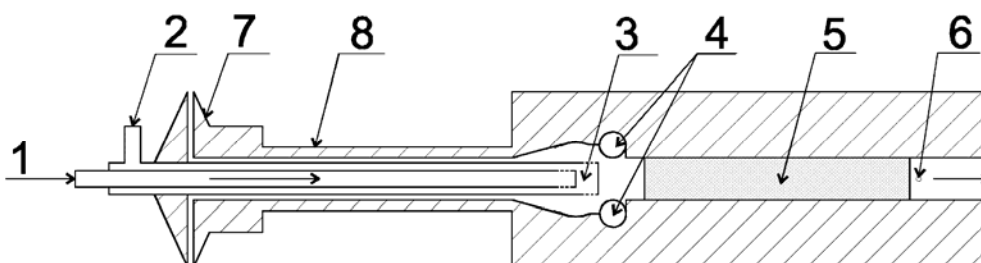


Fig. 1. Scheme of atomic iodine reactor with embedded reactor for generation of F atoms
 1 – NO inlet, 2 – F_2/N_2 inlet, 3 – generator of F atoms, 4 – HI injectors, 5 – optical cavity for ISD detection, 6 – thermocouple, 7 – input flange, 8 – delta-shaped channel

Atomic F was generated in the space of the inner coaxial reactor **3** with the tube **2** for inlet of the F_2/N_2 mixture and the tube **1** for NO inlet (2 mm i.d.) This coaxial reactor was inserted into a delta-shaped entrance space of the main reactor. Non-diluted NO was injected into the F_2/N_2 flow through 6 holes (0.3 mm i.d.) drilled in one row along the perimeter of the tube **1**. The gas with generated F atoms exited the reactor **3** through 24 holes (1.1 mm i.d.) drilled along the perimeter of its outer tube in three rows of 1.5 mm distant from each other. It was possible to shift the F reactor

and so vary the time interval between the exit of F atoms from F reactor and HI injection. Two tubes **4** of HI injectors with one row of 19 holes of 0.6 mm oriented perpendicularly to the primary flow were located in the reactor walls. Two side windows of the reactor served for detection of atomic iodine and recording its concentration profile along the flow in the reactor. The probe beam of the Iodine Scan Diagnostics (further ISD) passed through these wedge-shaped windows perpendicularly to the gas flow. A velocity of the probe beam moving along the duct axis was 4 mm s⁻¹. The ISD probe beam emitter/detector unit was mounted on the assembly of motorized linear positioning equipment controlled by PC making possible to record atomic iodine signal on the path of 13 to 60 mm distant from the axis of the injectors **4** (dotted area in Fig. 1). The F₂/N₂ mixture with 20 % F₂, non-diluted NO and HI gases were employed in these experiments. Experiments were carried out with rather high flow rates of reaction gases, 1.4 – 2.4 mmol/s F₂, 1.7 – 2.7 mmol/s NO and 1.3 – 3.3 mmol/s HI. The reaction system was exhausted with the rotary pump (30 m³ h⁻¹). The gas flow was throttled for attaining higher pressures.

2. Results and discussion

Fig. 2 shows the course of atomic iodine along the optical cavity in dependence on HI flow rate. At the lower HI glow rate this concentration was nearly constant along the optical cell. At the higher HI flow rate, the I concentration attained up to 4.2 x 10¹⁶ atom cm⁻³ and decreased moderately with distance.

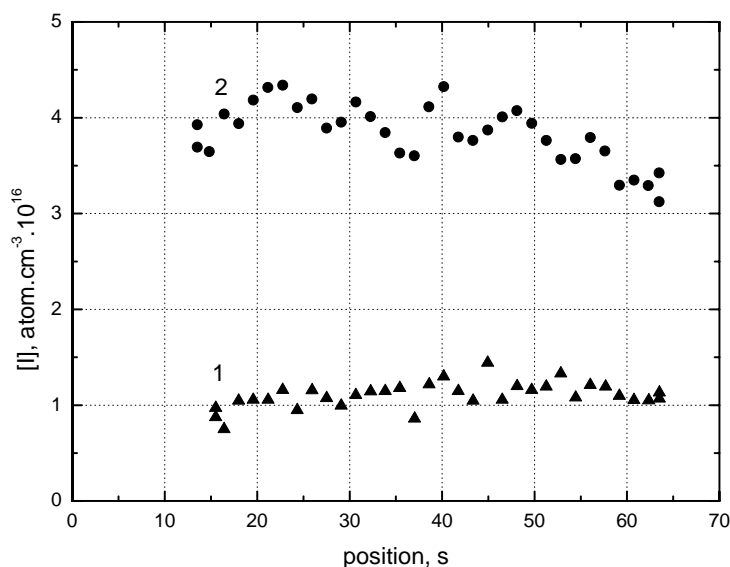


Fig. 2. Atomic iodine concentration recorded along gas flow at different HI flow rate (in mmol/s): 1 – 1.32, 2 – 3.4; 1.5 mmol/s F₂, 1.85 mmol/s NO, P_{tot} = 8.5 kPa (curve 1), and 12.5 kPa (curve 2)

Still higher I concentration was achieved after throttling the gas flow downstream the cavity. **Fig. 3** presents one example, where the I concentration was up to 8×10^{16} atom cm^{-3} at overall pressure about 30 kPa.

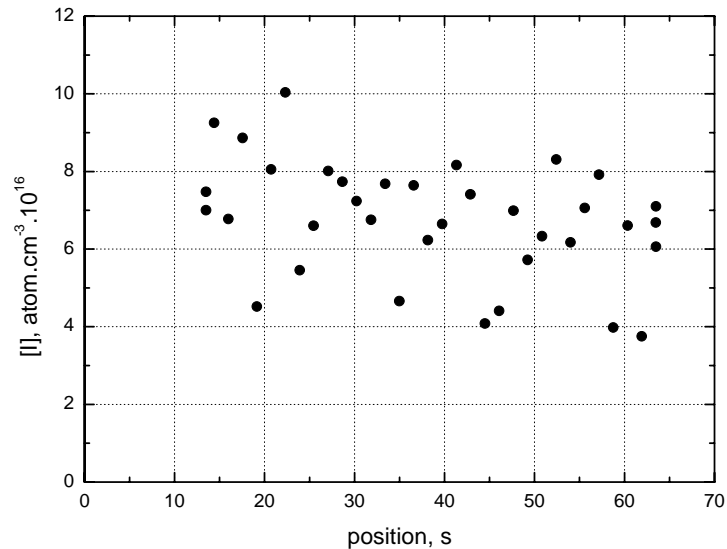


Fig. 3. Atomic iodine concentration recorded along gas flow at a total pressure of 30 kPa, gas flow rates: 1.5 mmol/s F_2 , 1.75 mmol/s NO , and 2.0 mmol/s HI

The yield of atomic iodine (vs. F_2) was between 30% and 40% in these measurements. Gas temperature evaluated from ISD measurement was from 900 K to 1500 K. At pressures over 20 kPa the temperature values were however very scattered most probably due to a line pressure broadening.

3. General conclusions following from the small-scale studies

The previous experimental and theoretical results, and the results examples given above document a principal possibility to produce effectively atomic iodine for the COIL operation by the proposed all-gas chemical method, and even at very high pressures. Employing of this method in the overall operation scheme of supersonic COIL needs however special conditions that are discussed further.

III. Analysis of possible schemes of F → I atoms generation, and I atoms injection into the primary O₂(¹Δ_g) flow in a COIL

1. Mixing of all reaction gases (i.e. F₂, NO, and DI) in the subsonic O₂(¹Δ_g) flow (upstream of the supersonic nozzle)

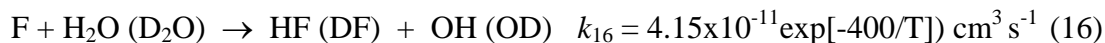
Using deuterium iodide, DI, instead of HI is necessary due to a fast quenching of I* atoms by HF, the by-product of reaction (2). Although this arrangement we used successfully on the supersonic COIL with the reaction system Cl → I, it is not suitable for the F → I system. The main reason is rather slow formation of F atoms (via reaction (1)) followed by generation of I atoms, a fast pumping to I*



and I* quenching by water ($k_{\text{H}_2\text{O}} = 2 \times 10^{-12} \text{ cm}^3 \text{ s}^{-1}$) present in the O₂(¹Δ_g) flow. In these conditions, a great part of earlier formed I atoms would be excited and quenched by water.

2. Generation of F atoms in a separate (side) reactor and injecting F atoms together with DI into the O₂(¹Δ_g) flow

This arrangement could meet a problem of fast reaction of F atoms with water molecules [4] coming from O₂(¹Δ_g) generator



The rate constant of this reaction is comparable with the constant of I atom production ($k_2 = 1.512 \times 10^{-10} \exp(-5057.8/RT)$). This circumstance would reduce significantly the production of I atoms both upstream and downstream the nozzle throat.

There is still another disadvantage of both above mixing schemes if they are applied upstream the nozzle throat (i.e. at pressure above 1 kPa (7.5 torr)). This is a partial quenching of O₂(¹Δ_g) that we observed after HI admixing upstream the throat. It was explained by the probable presence of HO₂ radical formed by the assumed reaction



We also observed a significant formation of I atoms after HI admixing into the O₂(¹Δ_g) flow [5]. In the Cl → I system, this process is not so detrimental due to the fast formation of both Cl and I atoms resulting also in a fast consumption of HI.

3. Generation of I atoms in a separate (side) reactor and injecting these atoms into the O₂(¹Δ_g) flow

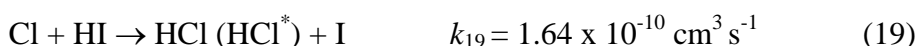
This scheme is based on the results of modeling and experimental studies presented above. These results proved attaining the high concentration of atomic iodine ($c_I \leq 8 \times 10^{16} \text{ cm}^{-3}$) with a moderate yield ($Y_I \leq 50 \%$) by mixing of 20% F₂/N₂ mixture, non-diluted NO and HI at a rather high total pressure (up to 30 kPa ($\cong 225$ torr)). It was also calculated (based on experimental results) that the loss of I atoms by heterogeneous recombination on the reactor walls and during injection into the primary flow could be limited up to several percent only. These findings showed that optimum scheme is the production of atomic iodine in separate reactors and injection of I atoms into the primary O₂(¹Δ_g) flow. Injection of I atoms downstream the nozzle throat is preferred, as it reduces the loss of I* atoms by water.

In accordance with the planned tasks of this grant, a new scheme of atomic iodine generation and injection will be tested. Due to hard requirements on the construction materials in the case of fluorine reaction system, the existing laser device employing the Cl→I reaction system is not suitable for this investigation. A new COIL device made mostly of stainless steel has been therefore designed and is under construction at present. Nevertheless, some model experiments before a definite construction of this new laser device were performed on the laser with the Cl→I reaction system to examine and optimize the supersonic mixing of iodine atoms with the primary flow. These results are presented in the next chapter.

IV. Generation of atomic iodine in two separate (side) reactors, and injection of atomic I into the primary supersonic flow (with the Cl → I reaction scheme)

1. Experimental

The experimental configuration is shown in **Fig. 4**, where atomic iodine is generated according to the known reaction scheme [5, 6]



This figure shows schematically two side reactors for generation and supersonic injection of atomic iodine into the COIL. This was studied first with the primary flow consisting of non-reactive He/N₂ mixture (1 : 4).

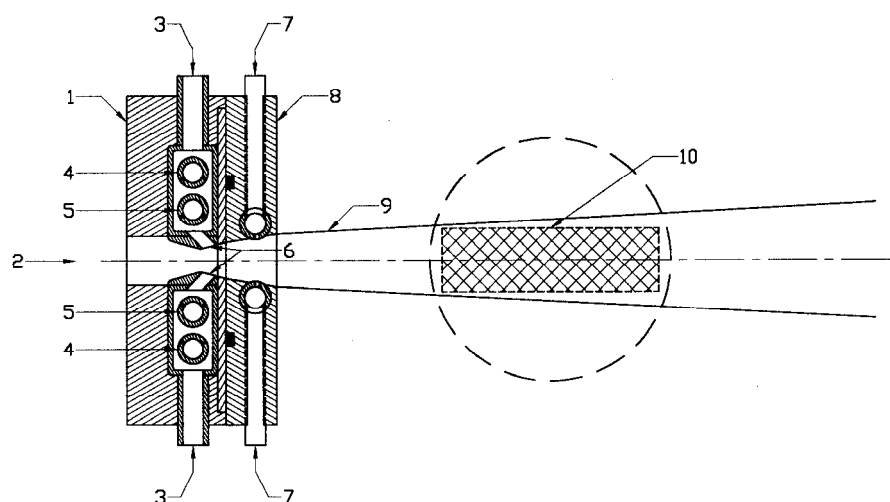


Fig 4. Cross section of the COIL nozzle with injection of I atoms from two side reactors

1 - reactor body, 2 - primary flow, 3 – ClO₂+secondary N₂ inlet, 4 – NO injector, 5 – HI injector, 6 – injection of I atoms, 7 – tertiary N₂ inlet, 8 – N₂ injector, 9 – supersonic nozzle, 10 – gain diagnostic region

Each reactor consists of rectangular space with the inlet for ClO₂, and injectors of NO and HI. Each NO and HI injector has 32 cylindrical holes of 0.4 mm i.d. and 0.3 mm i.d., respectively. Atomic iodine is injected from this reactor into the laser nozzle through 16 openings of 2.3 mm i.d in one row, and 15 openings of 0.8 mm in the second row, directed to the nozzle axis under the angle of 45°. The row of the 2.3 mm-holes is distant by 2 mm from the nozzle throat, and the row of 0.8 mm-holes is distant from it by 3.2 mm. The critical cross section of the nozzle throat is 50 mm x 5 mm. The injector for additional (“tertiary”) nitrogen joined closely with the injector of I atoms was installed to get better gas mixing in the slit nozzle. This injector comprises two 6 mm tubes, each having one row of 16 holes of 0.9 mm i.d. These tubes can be turned enabling to vary the direction of nitrogen injection. A channel height in this injector increases from 8.75 mm to 11.9 mm, and its length in the flow direction is 10 mm. The atomic iodine concentration was recorded in horizontal direction between 52 mm and 86 mm from the throat, and in vertical direction from 8 mm below to 8 mm above the nozzle axis. Designing of these reactors was based on the results of computational modeling of the whole reaction system including also the losses of atomic chlorine and iodine in ternary reactions with other reaction components. The NO and HI gases were undiluted (to suppress the ternary loss-reactions). The ClO₂ was diluted with nitrogen (1:10) for the safety reasons.

2. Results and discussion

Fig. 5 shows a concentration profile of atomic iodine across the cavity, measured at 59 mm from the nozzle throat (the optical axis of the resonator). The curve 1 with a maximum near the cavity center was measured without a primary gas. The gas temperature was rather high (375 K) and uniform (see curve 1 in Fig. 6).

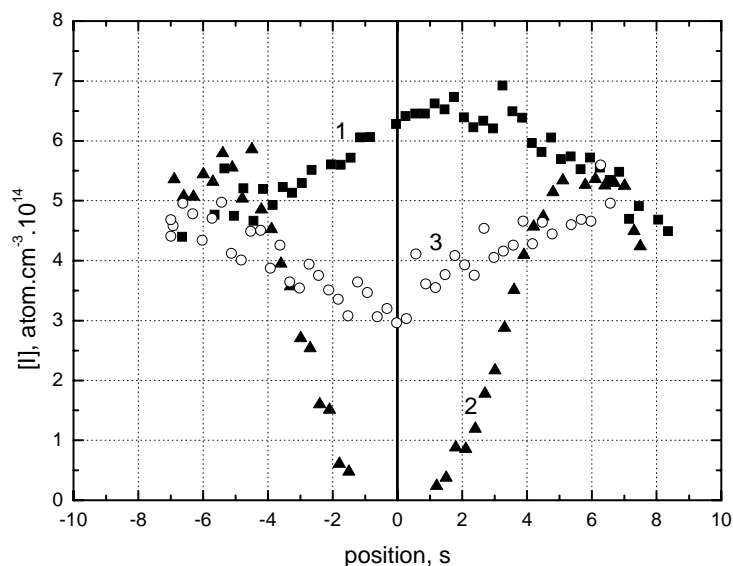


Fig. 5. Concentration of atomic iodine across the laser cavity at NO – HI injection order in the reactor. Effects of primary and tertiary gases
Flow rates (mmol s^{-1}): primary gas: 1 – no, 2 and 3 - 102 He + 32 N₂, secondary gas: (1.5 ClO₂ + 15 N₂) + 3.3 NO + 1.5 HI, tertiary gas: 1, 2 – no, 3 – 27 N₂

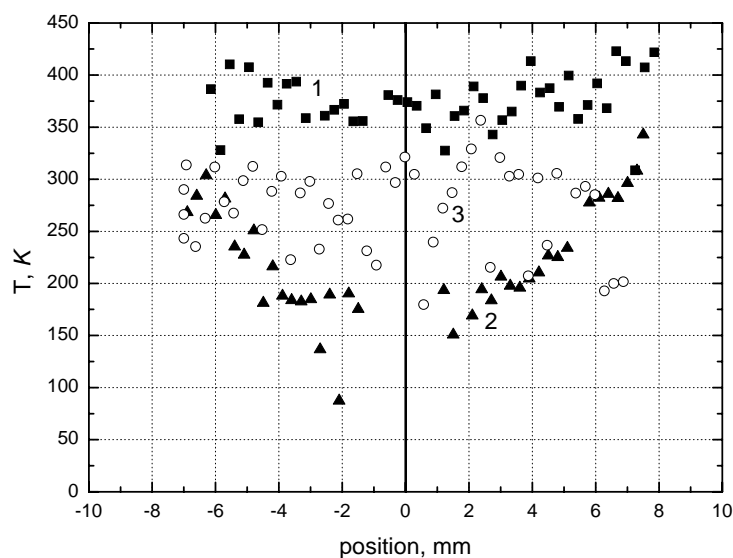
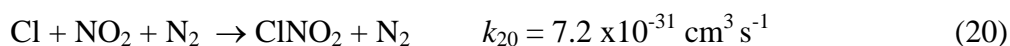


Fig. 6. Gas temperature profile across the cavity. Effect of primary and “tertiary” gases. Conditions and labeling as in Fig. 5.

The concentration profile dramatically changed when the primary gas was introduced (the curve 2). The gas temperature also declined significantly due to dilution of secondary gases by primary gas, and by the isentropic cooling. On the other hand, a high momentum of primary gas and low flow rate of secondary gas (due to using undiluted NO and HI) caused a low penetration of secondary gas with I atoms. The concentration profile of iodine atoms became very non-homogeneous, and even with zero concentration in the cavity center. Therefore, we tried to increase the penetration of injected I atoms by introducing tertiary nitrogen ($N_{2\text{tert}}$, see item 8 in Fig. 4). This procedure helped indeed to homogenize iodine concentration in the cavity (the curve 3 in Fig. 5), and also increased the I yield from 43% to 55%. This increase can be explained by a better mixing of reacting gases in the supersonic region. It followed from both this result and the modeling of the reaction system that atomic iodine is generated partly in the supersonic nozzle. Introducing the tertiary nitrogen, however, reduced the Mach number (in the cavity center from 2.3 to 1.8) and enhanced the gas temperature by about 100 K.

An increase in the ClO_2 flow rate by 50% at the same NO: ClO_2 ratio enhanced the I production by 38%. An increase in NO flow rate (for NO: ClO_2 ratio from 2.5 to 3.9 at 1.6 mmol/s ClO_2 , 1.8 mmol/s HI, and 20 mmol/s $N_{2\text{tert}}$) had no effect on the I production. The I concentration was $3 \times 10^{14} \text{ cm}^{-3}$ in the cavity center and $6 \times 10^{14} \text{ cm}^{-3}$ in two maxims distant 2 mm from the cavity walls. An increase in the HI: ClO_2 ratio (between 0.9 and 1.8) had only a weak effect in the measurements, where NO was injected first (through injectors 4 in Fig. 5) and HI second (through injectors 5) into the ClO_2/N_2 flow.

A substantial improvement of iodine atoms production was achieved with the reverse injection order of NO and HI. **Fig. 7** illustrates effects of NO and tertiary N_2 flow rates at this configuration on the production of atomic iodine. With the NO-HI injection order, Cl atoms are efficiently consumed after their formation by the fast reaction (19) and consequently their concentration is low. It results also in the low rates of loss reactions involving Cl atoms. The most serious loss is in the ternary reaction with NO_2 and nitrogen.



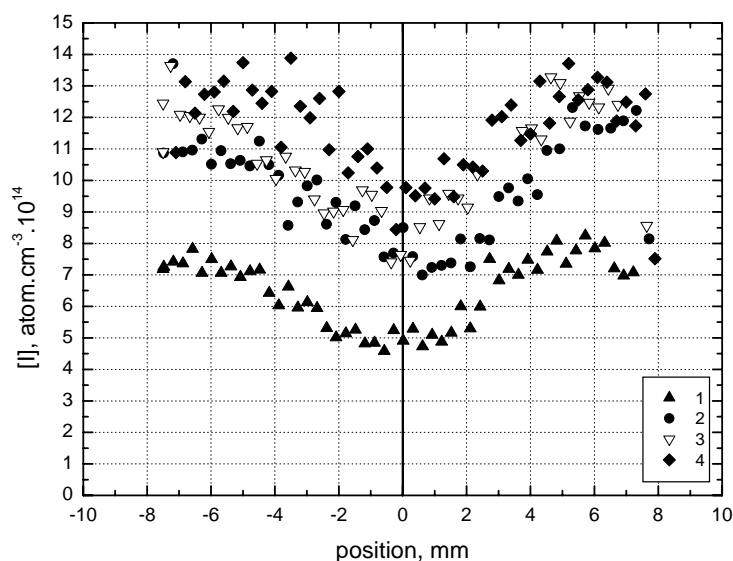


Fig. 7. Concentration of atomic iodine across the laser cavity at HI – NO injection order. Effect of NO and $N_{2\text{tert}}$ flow rate
 Flow rates (mmol s^{-1}): primary gas: $108 \text{ He} + 34 \text{ N}_2$, secondary gas: $(1.6 \text{ ClO}_2 + 13 \text{ N}_2) + \text{NO} + 1.8 \text{ HI}$, Curve 1 – $3.1 \text{ NO} + 21 \text{ N}_2(\text{t})$, 2 – $4.5 \text{ NO} + 28 \text{ N}_2(\text{t})$, 3 – $6.2 \text{ NO} + 28 \text{ N}_2(\text{t})$, 4 – $6.2 \text{ NO} + 37 \text{ N}_2(\text{t})$

Another reason for a higher I production at HI-NO injection order can be a shorter contact time of the mixture ClO_2+NO in the reactor. A higher fraction of Cl and I atoms is then formed in the supersonic nozzle where the pressure is markedly lower and so the ternary loss reactions are suppressed. In the NO-HI injection configuration, the regions with a high local concentration of Cl atoms (surrounding NO jets) and low HI concentration are formed, where loss-reactions like (10), (11), and (20) are accelerated. We confirmed these assumptions by the 2-D and 3-D modeling.

Working with higher flow rates of ClO_2 , NO, HI, and $N_{2\text{tert}}$ enabled to increase the average I concentration in the cavity up to $1.6 \times 10^{15} \text{ cm}^{-3}$ (see **Fig. 8**), which is about twice more than the maximum concentration attained with the subsonic mixing of the same reaction gases (but with NO and HI ten times diluted with N_2) [5]. The I yield was up to 100% in these measurements. Mixing of reacting gases in the separate reactors with following injection downstream the nozzle throat has also the advantage of much lower reaction rate of HI with $\text{O}_2(^1\Delta_g)$ than at mixing upstream the nozzle. Our previous studies with subsonic mixing proved that this reaction can reduce the I yield. We assume that also the small signal gain values in $\text{O}_2(^1\Delta_g)$ flow will be higher than the gain obtained with subsonic mixing of reactants [5].

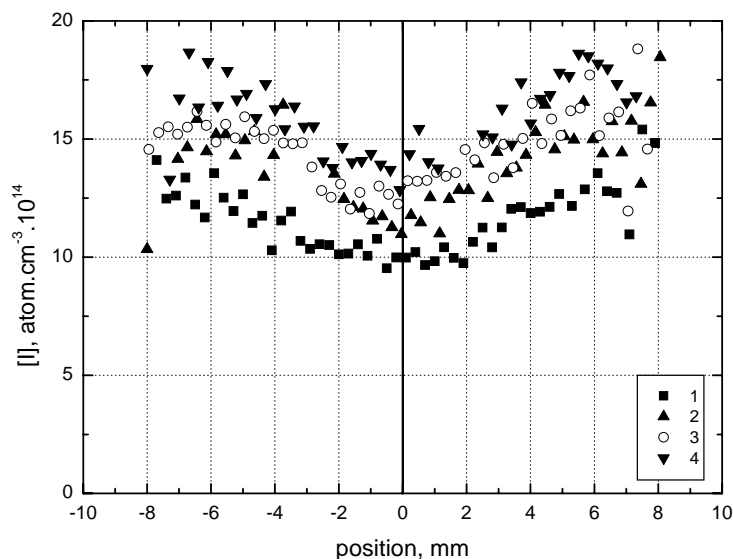


Fig 8. Concentration of atomic iodine across the laser cavity at HI – NO order.
 Effect of HI and NO.
 Flow rates (mmol s^{-1}): primary gas: 111 He + 33 N₂, secondary gases: (2.3 ClO₂ + 18 N₂),
 curves 1-3: 6.6 NO, curve 1: 1.34 HI, 2: 2.3 HI, 3: 3 HI, 4: 7.5 NO + 3 HI, 33 N_{2tert}

V. Design of supersonic laser device with atomic iodine generation via F atoms

Designing of the laser with atomic iodine generated via F atoms was based mostly on experimental results obtained on the small-scale reactors.

1. Overall scheme of the laser

The overall scheme of the laser device is shown in **Fig. 9**. The BHP liquid is prepared and cooled in tank **1** made of industrial glass. After opening the valve below the tank, the BHP liquid flows through the jet generator **2** into a lower tank. A BHP single pass burn down is employed. The collected liquid is re-pumped after experiment to the tank **1**. Singlet oxygen flow exits the generator, passes through the injector of atomic iodine **3**. The gas stream is accelerated in the nozzle **4**, and passes through the inlet element **6** into the vapor trap **7**.

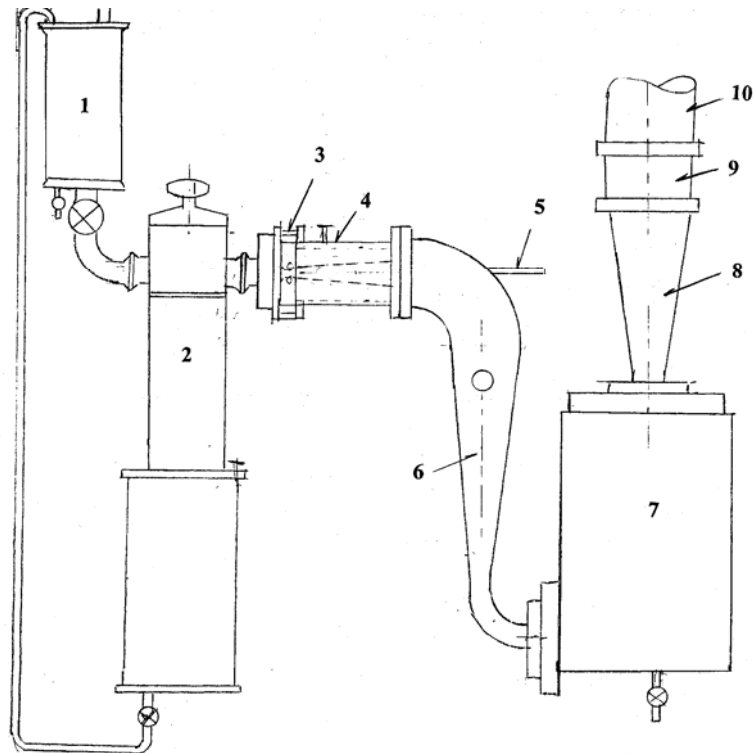


Fig. 9. General scheme of F-I laser device
 1 – BHP tank, 2 – JSOG, 3 – reactor-injector of atomic iodine, 4 – nozzle body,
 5 – Pitot tube, 6 – inlet delta element, 7 –vapor trap, 8 – exit delta element,
 9 – square-circle adaptor, 10 – vacuum piping (d = 150 mm)

2. Singlet oxygen generator

During the first experimental period, we plan to operate the COIL with an older type of the jet SOG (item 2 in Fig. 9) used in our former COIL device. This SOG has a counter-flowing gas-liquid arrangement and horizontal gas exit. A detailed description of the SOG design was given in the EOARD Final Report [7].

3. Reactor-injector of atomic iodine

The reactor body (item 3 in Fig. 9) is made of stainless steel. A technical drawing of the one half of central part of vertical cross-section of this reactor (in the region of gas channel) is shown in **Fig. 10 (Appendix)**. The oblique abscissa in the upper-left corner represents the wall upstream of the nozzle throat, and the part of the circle in the upper right corner one nozzle wall. The edge in the center will create the critical section of the nozzle (40 mm x 3.5 mm) after welding together two halves of the body. The oval opening in the center forms the inner space of one reactor (with the exception of 6 mm tube of HI injector that is inserted into the reactor – this tube is not shown here). Tube injectors for F_2/N_2 mixture, and NO are inserted into two cylindrical holes of diameter 6.2

mm. The secondary gas exits the reaction space through two rows of conical holes of diameters 1.4/1.9 mm and 0.6/0.9 mm, respectively.

4. Nozzle body

Technical drawings of the vertical cross-section of the nozzle body, its section plan, and projection are shown in **Fig. 11 (Appendix)**. The oval opening on the cross section serves for exit of the laser beam into the resonator arms. Four screws M8 fasten each arm to the nozzle body. Ceiling of the nozzle body is equipped with two 4.2 mm openings for the static pressure measurements. First part of the supersonic nozzle is formed in the reactor body (see Fig. 10), and the second part of the nozzle is created by two ramps (not shown here) that are inserted into the nozzle body. The upper and lower walls of these ramps form an angle 2° with the nozzle axis.

5. Inlet delta element with Pitot tube

A side cross-section of the upper part of the inlet delta element is shown in **Fig. 12 (Appendix)**. It is bended because of space needs. Vapor trap is placed much lower than the laser body because it will be cleaned after finishing experiments by filling with $\text{Na}_2\text{S}_2\text{O}_3$ solution and afterwards rinsed with water. Fig. 12 shows also the holder of the Pitot probe tube that enables shifting this tube (not shown here). Entrance of this element has inner dimensions 40 mm x 40 mm, and the exit into the trap 28 mm x 400 mm.

6. Trap with inlet and outlet delta elements

Fig. 13 (Appendix) shows unit block layout of vapor trap with inlet and outlet delta elements. Both delta elements are made of 4 mm-thick stainless steel plates welded together. Outer case of the trap is made of 30 mm-thick Plexi-glass plates (used in our lab earlier). Trapping of vapors (water, I_2 , NOF, DF, residual NO, DI, and Cl_2 , respectively) will occur on the cooler consisting of 18 copper 1 mm-thick plates of 25 cm x 15 cm that are distant from each other by 2 cm in the first half of gas path. In the second half of gas path, there are additional 17 copper plates of 12.5 cm x 15 cm that creates together with former plates only 1 cm gaps. The trap is cooled with liquid nitrogen.

The laser system is exhausted with the rotary pump ($300 \text{ m}^3 \text{ h}^{-1}$) coupled with a Roots pump ($1800 \text{ m}^3 \text{ h}^{-1}$).

Most of individual elements of the new laser device have been already fabricated. **Fig. 14** shows, for example, a photo of the laser body with the central channel for insertion of the nozzle ramps and two oval openings for the laser beam exit. This oval make possible to vary a distance between the

nozzle throat and axis of the optical resonator. **Fig. 15** shows the input delta element of the trap with the Pitot tube holder.

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Appendix – Technical drawings and photos

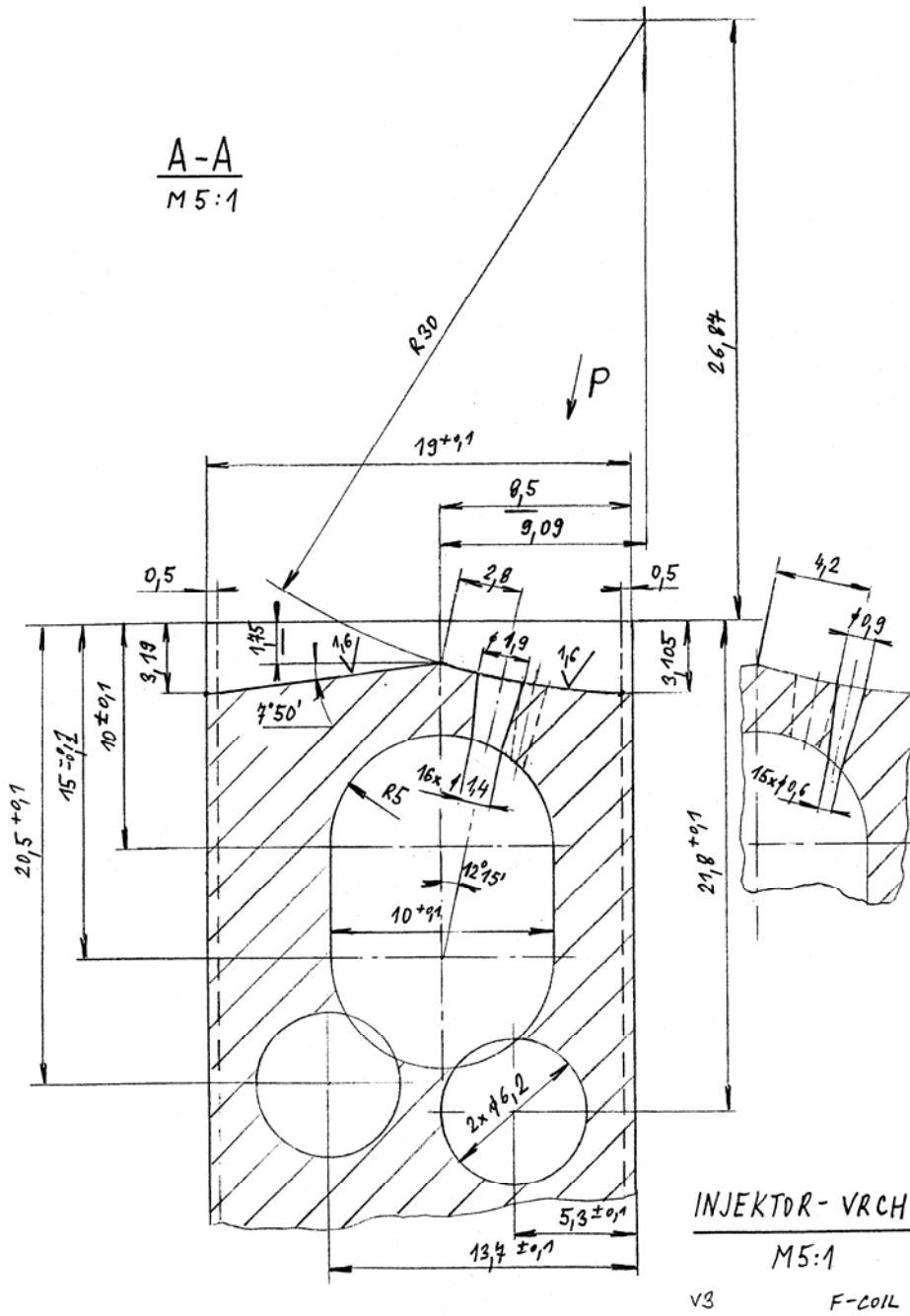


Fig. 10. Cross-section of one reactor-injector of atomic iodine



Fig. 14. Photo of the laser body



Fig. 15. Photo of the delta input element of the vapor trap