Electronic Supplementary Material (ESI) for RSC Sustainability.
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Supporting information for "Solvent Extraction of Gold with Biomass Chemicals".

Contents

Materials

The HVO100 biodiesel was produced by Neste and purchased from the Tanka filling station which is at the Lidbil garage at Torggatan 54 in Vara. The fuel was purchased on the 10th of May 2022. To safely transport the HVO100 away from the filling station and to comply with the regulations associated with the sale of motor fuel to the general public a painted (purple) 5 L steel motor fuel can was purchased from Bildelen Nordstrom in Vara (A town of *circa* 4200 people in Västra Götaland County in Sweden close to the E20 road and the railway track between Borås and Uddevalla). The HVO100 was dispensed on a fine day without rain from a pumping machine designed for fueling cars at 13:27 Paris time into the steel fuel can. The pumping machine has a hose and nozzle which is dedicated for the dispensing of the Neste biodiesel. The HVO100 fuel was transferred to borosilicate bottles before being used in the experimental work.

The medical grade paraffin sample (300 ml) was produced by APL (Prismavägan 2, 141 75, Kungens Kurva, Sweden) and was purchased via the web sites of Apotea AB. The full name of APL is Apotek Produktion & Laboriatorier, which is a state owned company. Their telephone number is +46(0)10 447 9600 and their website is at www.apl.se.

The lamp oil was purchased from the museum shop at Cesarstugan (Falköping 521 94, Sweden).

The malonamide extractant was prepared during the PhD studies of Mikhail. by the reaction of diethyl malonate and *bis*-(2-ethylhexyl) amine. It had been vacuum distilled before bottling. Note that the malonamide is very viscous and difficult to pipette. Cyanex 923 was supplied by Cytec some years ago before in 2015 it was acquired by Solvay. Note Cytec was a spin off company from the American Cyanamid Company. Cyanex 923 is a mixture of long chain trialkyl phosphine oxides which is a liquid at room temperature.

Scrap gold in the form of damaged jewellery was purchased from a pawnbroker (Pantbanken Sverige) which is at Norra Hamngatan 36, 411 06 Gothenburg (Göteborg) in Sweden. The gold was 18 Karot gold (810 mg) which is believed to have been an earing. The jewellery was flattened by hammering it against a steel surface while it was wrapped in paper to increase its surface area. The gold was combined with 16 M nitric acid (5.595 grams) and 12 M hydrochloric acid (4.47 grams). After allowing this to stand (90 minutes) it was diluted with water to a volume of 60 ml. The slurry of silver chloride and the gold solution was transferred to polyethene centrifuge tubes. After centrifugation (3000 rpm five minutes) the supernatant was transferred to a polyethene tube. It was then transferred in small amounts into a borosilicate beaker (20 ml) in which it was reduced down by evaporation by heating on a hot plate in a fumehood to a volume of *crica* 3 ml. The deep green liquid was transferred to a 15 ml polyethene tube before the beaker was rinsed with water (2 ml). The rinse water was combined with the gold stock in the polyethene tube. Examination with ICPOES indicated that this gold stock contained 19581 ppm of copper (2 %) and 102531 ppm gold (10.3 %)

Alumina (particle size 0.063 to 0.200 mm, 70 to 230 mesh) was supplied by Merck. The product was aluminiumoxide 90 which is article number 1097 and was Brockman grade with an activity between II and III. The specification for this grade of alumina is that a 10 % slurry in water will have a pH between nine and ten.

Argon gas for the ICPOES and ICPMS machines was supplied by AirLiquid in 50 L cylinders.

All other chemicals unless otherwise stated were supplied by Aldrich.

Instrumentation

For the experiments with lower metal concentrations an iCAP Q Inductively Coupled Plasma Mass Spectrometer (ICPMS) supplied by Thermoscientific was used. The machine is equipped with a ASX520 sample changer

For the experiments with higher metal concentrations an iCAP Pro Inductively Coupled Plasma Optical Emission Spectrometer (ICPOES) supplied by Thermoscientific was used. The machine is equipped with a ASX560 sample changer.

Gas chromatography mass spectroscopy experiments were conducted with a 7820A gas chromatography machine supplied by Agilent (A company formed when HP {Hewlett-Packard split off the medical products, chemical analysis and other instrumentation section into a new company}). The machine was fitted with a HP-5MS column. Coupled to the 7820A is a 5977E MSD mass spectroscopy detector. The column length is 30 meters, the bore of the column is 0.25 mm. The thickness of the coating is 0.25 micron. The inlet temperature is 250 ^{o}C, aux1 (transfer line) is 280 ^{o}C, the MS source is at 230 ^{o}C and the MS quadrapole is at 150 ^{o}C. The injection volume is 1 microlitre, injected at a rate of 3 ml min-1. The column starts at 60 ^{o}C, is held for 1 minute after injection before being heated at 20 ^{o}C min^{-1} to 300 ^{o}C. After a dwell time of 2 minutes the acquisition is halted and the column oven allowed to cool.

Alpha counting was done using an ORTEC semiconductor detector using samples dispersed on stainless steel planchets. It is important to obtain a thin film of the active material on the planchet, the samples were heated first with an infra red lamp and then with a butane / air flame. After cooling the samples were transferred into the counter. The gap between the sample and the detector was a vacuum (oil filled rotary roughing pump)

Liquid scintillation counting was performed using a Wallac Guardian 1414 liquid scintillation counter supplied by PerkinElmer life sciences. Glass scintillation counting vials (7 ml) were used. Diluent samples were examined using Emulsifier Safe cocktail while for urine samples Hionic Fluor was used.

Grinding of printed circuit boards was done using a Retsch SM300 mill operated at 3000 rpm. For the first grinding campaign a fine sieve was used in the mill to prevent oversized particles entering the product hopper. For the second campaign a coarse sieve (4 x 4 mm holes) was used. The solid product from the second campaign was sieved using a series of stainless steel sieves. The hole sizes on these sieves were 4, 2, 1.4, 1, 0.71, 0.18 and 0.09 mm. The stacks of sieves were shaken using a Retsch AS200 shaking machine. Samples of the different size fractions were digested with *aqua regia* before the solutions were examined with ICPOES. External calibration was used for these experiments.

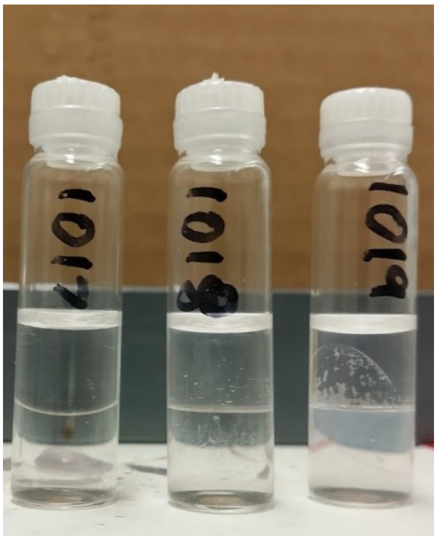
Methods

Distribution ratios

Distribution ratios were determined by shaking the denser phase with the light (organic) phase in a glass vial which is equipped with a polyethene lid. After shaking the lower layer was sampled using an air displacement pipette (1000 μl) equipped with a polyethene tip. The general method is the same as was used before in Foreman's group at Chalmers. If needed for a stripping experiment the organic layer was transferred from the vial using the same equipment.

A typical experiment was conducted in the following manner, a glass vial was labelled with a serial number and fitted with a push on cap. The mass of the vial was recorded, to the vial was added between 500 and 700 μl of the denser phase. The vial was recapped and the gross mass determined again. Then the lighter (organic) phase was added, we aimed to keep the volumes of the two phases equal. The vial was recapped and the mass determined again. Then parafilm (a blend of polyolefins and paraffin wax) was wrapped around the union between the glass vial and the polyethene cap. Note with some plastic caps a failure to do this step will result in the lid coming off the tube during shaking. The tube was placed inside a thermostated shaking machine where it was shaken (60 minutes). After shaking the tube was centrifuged before being opened.

The shaking tubes were examined after the centrifugation, shaking tubes which had solid particles in either liquid layer or at the interface were rejected.



Additionally if the organic phase split from one phase into three phases then the tube was rejected. In one case the organic phase split into two layers one was presumed to be diesel fuel rich and the other contained mainly extracted metal complexes with the extractant. For information below is shown a photograph of three tubes where the organic phase has split into two layers thus giving three layers in the tubes.

The air displacement pipette has a button on the top, we use adjustable pipettes which are purely mechanical they contain no electrical parts. We start by fixing a tip to the pipette, next using a thumb we press down to the first stop. Then we insert the tip of the pipette into the lower phase in the vial, with a little additional force on the button we blow out a bubble from the tip to clean any organic phase out of the tip. Then we slowly relax the force on the button to allow it to rise to the top of its travel while keeping the pointed end of the pipette in the lower phase. When no force is on the control button on the top the pipette is raised thus taking the tip out of the vial. The outside of the tip is wiped with paper towel before the liquid in the tip is dispensed (by pushing down on the button) into a preweighed 15 ml plastic (polystyrene, polyethene or polypropylene) vial. The new mass of the vial is recorded and then to the vial is added dilute mineral acid (9.5 ml of matrix acid) to dilute the sample for either the ICPOES or ICPMS machine. The vials were then capped, weighed and then shaken before use.

While in the past in the Foreman group it has been common to use ruthenium as an internal standard for ICPOES, it was found while working on the TARANTULA project that when oxalic acid was added to the matrix acid that the ruthenium disappeared from solution. As a result we changed to using rhodium (1 ppm) for ICPOES work when we had oxalic acid present in the acid. The oxalic acid was used to modify the behaviour of niobium and tantalum. As the 2 litre polyethene bottle used to hold high purity hydrochloric acid was contaminated with oxalic acid from recent TARATNULA project experiments on niobium / tantalum we choose to continue to use rhodium as the internal standard.

For ICPMS work we used hydrochloric acid diluted in MQ water with a lower concentration of rhodium as the internal standard. For gold work in the ICPMS it is important to add a sulfur containing matrix modifier, we use the amino acid methionine at 10 grams per litre (1 %).

Chloride concentration of choline chloride stock

The chloride concentration of choline chloride stock solution was determined by titration with silver nitrate solution (0.10011 M) using potassium chromate as an indicator. The titration used a manual burette (50 ml) which is held using a burette clamp which is attached to a clampstand. As the majority of the clamp stands in the Foreman lab have had their bases painted with red hammerite to reduce the formation of rust and other corrosion products, a sheet of white paper (paper hand towel) was placed under the conical flask which holds the chloride solution being titrated. The clamp stands were treated first by brushing with a steel brush and soaking in oxalic acid to remove rust deposits before being dried. Then they were painted using red hammerite.

Titration run	1	2	3	4	5
Volume of choline chloride stock (ml)	0.500	0.800	0.800	0.800	0.800
Mass of choline chloride stock	0.5546	0.8725	0.8758	0.8597	0.8915
Density	1.109	1.091	1.095	1.075	1.114
Volume of silver nitrate solution used	27.1	41.75	43.55	42.7	44.2
Volume of silver nitrate solution per mililiter of choline chloride stock	48.68	47.85	49.73	49.67	49.58
Concentration choline chloride (moles per litre)	4.87	4.79	4.98	4.97	4.96

Average value 4.914 moles per litre.

Average density 1.097 grams per ml

Acid Base Titration method

A dilute sodium hydroxide solution was made by dissolving sodium hydroxide pellets (8.0741 g) in a glass volumetric flask (2 L). After the dissolution of the pellets the volume was increased to 2 L. A dilute nitric acid solution was made by diluting concentrated nitric acid (6.25 ml) to 2 L in a volumetric flask.

To obtain the ratio of volume between the sodium hydroxide and the dilute nitric acid four separate portions (10 ml) of the sodium hydroxide solution were spiked with bromothymol blue solution and were titrated with the nitric acid. The volumes used were 18.2, 18.0, 17.8 and 17.9 ml. It was calculated that the volume ratio between the nitric acid and the sodium hydroxide was 1.7975 : 1.0000

To standardize the solutions a known volume (0.5 ml) of a 1 M sulfuric acid volumetric standard (Purchased from Aldrich) was combined with our dilute sodium hydroxide solution (20 ml), this mixture was spiked with bromothymol blue and then titrated with the dilute nitric acid. In three experiments 17.55, 17.55 and 17.50 ml of nitric acid were used. It was calculated that the dilute nitric acid was 0.0543 moles per litre.

Thus the dilute sodium hydroxide is 0.0976 moles per litre.

Liquid scintillation counting method for the determining of the solubility of water in a diluent

WARNING: In the same way as it would be the height of folly to attempt to do lion taming, ride a motorcycle, handle highly venomous snakes (such as cobras), fly an aircraft, prepare puffer fish for human consumption, do high voltage electronics and perform dentistry without being properly taught how to perform these actions. It is equally inadvisable to for the ordinary chemist to perform radiochemistry without specialist training.

Equally even while one of the authors (MF) has training both in radiochemistry and high voltage electronics it would be inadvisable to perform such work without the correct plant and equipment present. For example one should not perform radiochemistry either on the kitchen table or in a normal chemical laboratory where the room is not designed / built / operated in such a way to prevent the spread of radioactivity and facilitate decontamination. Equally I would not attempt to work on a 4 x 3CX800A7 amplifier (One was marketed by Linear Amp UK with the poetic name "Invader") in a place where children have access to the equipment if I was the only person present with experience of high voltage electronics (My reasoning is if I have to leave the room then I have the potential to leave a child with access to a high power high voltage rig). To get the full 3 kW output from the amplifier I would need a 2200 volt DC supply for the anodes which is able to deliver 1 A to each valve.

Also however well equipped and well trained you might be, there will be times when you are unfit to perform some types of work. Ignoring workers impaired by medication, alcohol or other street drugs it is important to note that even a common cold can render you unfit to perform some types of work. If you think you might be ill you should strongly consider if you are fit to perform work with either radioactive or nonradioactive chemicals in a chemical laboratory.

Tritium (^3H) is radioactive, open sources of tritium should only be used by a trained radiochemist working at a site suitably equipped for such work. Note that it is impossible to measure tritium with a Geiger-Muller tube detector as the low energy of the beta particles make them unable to pass through the mica window of a GM tube used for beta emitters.

Now after being suitably warned here is the experimental method. As you will later discover the world's worst radiochemist is able to do themselves less harm with the tritium stock needed for the experiment than it is possible to do to one's self in a traditional organic, inorganic or organometallic chemistry laboratory.

Scintillation cocktail was dispensed into glass scintillation vials. It is important for reasons of radiological safety to place the cocktail in the vial before a radioactive solution. A general rule in radiochemistry is to always where possible add the radioactive solution last to a vial, this reduces the number of operations where open containers of radioactivity have to be manipulated.

Before performing the radioactivity work a layer of clean paper towels were laid on the floor of the fumehood. Their purpose is to both provide a means of soaking up a spill and to also provide a clean (uncontaminated) surface inside the hood. At Chalmers in nuclear chemistry unless a radiochemical hood has been completely emptied, thoroughly cleaned and verified by the radiation protection officer to be free of contamination it is treated as if it is contaminated. Objects may be passed freely into the hood but the vast majority of objects are only allowed out of the hood if they are sealed inside plastic bags.

It is normal to wear a disposable gloves if one needs to touch an object or surface inside the hood. For most of the work MF worn one glove, one hand is considered to be the "dirty hand". The dirty hand manipulates radioactive objects while the clean hand (ungloved) holds the pipette handle, when more than 1 kBq of activity is being pipetted then a filter pipette is used to prevent the transfer of droplets into the pipette. As the 200 microlitre pipette had to reach deep inside the polyethene tube holding the diluted tritium stock solution, the majority of the shaft of the pipette was wrapped with parafilm from the bottom up in a spiral manner. Outside the hood glass vials had the diluents added to them and were placed inside small plastic pots to prevent them falling over or touching the paper. The tritium solution was added to the glass vials, these were capped. A loose tag was left on the parafilm which allows a gloved hand to hold the parafilm before the clean hand rotates the pipette thus unwinding the protective parafilm layer from the pipette shaft. Then the tip was ejected from the pipette into a rigid waste container to which was added the parafilm.

The capping and decapping process processes required both hands, for these operations gloves were worn on both hands. After capping the vials they were shaken by hand before being allowed to settle (90 minutes). The tubes were opened before samples (500 microlitres) were withdrawn from them using a 1000 microlitre pipette. Before sucking up the sample into the pipette a liquid scintillation vial was prepared and placed in clean plastic beaker, the sample of the diluent was dispensed into the liquid scintillation vial with great care to avoid contamination of the outer surfaces of the counting vial. Then the cap was screwed onto the vial with an ungloved hand before the vial was lifted out of the hood using an ungloved hand. It is important to shake the vial until the contents of the vial is homogeneous. If the contents after shaking is cloudy or otherwise not homogeneous then the sample volume is excessive.

The labels for the tubes were written on the lids, the tubes were then placed in the liquid scintillation counter for measurement.

Note that these instructions are provided for information alone, merely reading them will not enable a person without experience / training of working with open radioactive sources to perform the work without the supervision of a radiochemist. Also note that the methods and systems of work used at different radioactivity sites vary, so a trained nuclear / radioactivity worker will always need site specific training.

For example consider shoes for use in radioactivity areas. While visiting the waste vitrification site at Sellafield I was issued with black steel toe capped shoes for use in the radioactive area (C2 level), while at nuclear chemistry in Chalmers black clogs are used in rooms where no or a little radioactivity is handled. For a higher contamination level at Chalmers we use a white clog, in the event that we have to walk on an exceptionally contaminated floor we tend to put overshoes onto white clogs.

At Chalmers we work in such a way that we confine the radioactive contamination to the inside of our fumehoods and gloveboxes. An event which causes radioactivity to appear on a surface outside the fumehood such as on the floor is regarded as a radioactivity spill and is promptly dealt with. We use white clogs in areas where greater amounts of radioactivity are handled as the floor has a greater potential to be contaminated (We still aim to keep the floor free of contamination).

I was informed by the late John Peckett that at Harwell in radioactivity areas which would correspond to a C2 at Sellafield or blue area at Ringhals that the shoe used was a red leather shoe. While at Ringhals (A Swedish nuclear site) I wore blue push on shoes in areas which have the potential for slight contamination on the floor (Blue areas). It should be clear that as the nuclear / radioactivity sector does not have a uniform policy on the colour of the shoes one wears in a room where the floor is likely to be uncontaminated but has the potential to be contaminated, it should be obvious that even an experienced radioactivity worker will need some site specific training if they need to perform work at a new site.

Experiments

Experiment 1

A solution of the malonamide in untreated HVO100 was made by dissolving *circa* 0.5 ml (0.4206 g) of the malonamide in the diluent (4.5 ml of HVO100, 3.4284 g).

A solution of gold and copper in a mixture of sodium and hydrogen chlorides was made up according to the following table.

Substance	Volume (ml)
Distilled water	8
Hydrochloric acid (2 M)	1
Saturated sodium chloride solution	1
Gold stock from scrap jewellery	0.1

The solution of gold and copper chlorides from the gold scrap was combined with water, dilute hydrochloric acid and saturated sodium chloride solution. This was pipetted into a series of nine shaking vials (970 to 978). To three of the vials was added the HVO100, to three the solution of the malonamide in HVO100 and to three was added a hydrocracked HDO fuel from skyNRG. The vials were shaken by hand for one minute before being centrifuged (4000 rpm for ten minutes).

In the tubes (970, 971 and 972) which contained HVO100 and the copper / gold solution a solid was observed at the interface between the two liquids. This formation of crud makes it impossible to measure the distribution ratio and thus these tubes were not sampled. The tubes were then subject a second centrifugation at 5300 rpm for 10 minutes, this failed to resolve the third phase problem.

Tubes (973, 974 and 975) which contained the malonamide solution in HVO100 had two homogeneous layers in them, so they were then sampled. Tubes (976, 977 and 978) contained the skyNRG fuel, these in common with tubes 973 to 975 had two clear layers in them. Thus they were sampled. For the tubes using skyNRG only 400 microlitres was used of each phase

	Shaking vial			ICP Tube		
Shaking tube	Empty	With aqueous	With both layers	Empty	With sample	With sample and acid
970	3.4167	4.1388	4.6808	**CRUD**	**CRUD**	**CRUD**
971	3.4080	4.1397	4.6923	**CRUD**	**CRUD**	**CRUD**
972	3.3979	4.1315	4.7002	**CRUD**	**CRUD**	**CRUD**
973	3.3130	4.1475	4.6891	7.7230	8.1553	17.7465
974	3.4191	4.1550	4.7128	7.7014	8.1542	17.7754
975	3.4331	4.1699	4.7379	7.6779	8.1154	17.7541
976	3.4010	3.8204	4.1211	7.7106	7.9266	17.5625
977	3.4028	3.8247	4.1309	7.6848	7.8905	17.5175
978	3.4074	3.8294	4.1403	7.6622	7.8721	17.5093
Starting solution	-	-	-	7.6836	8.0981	17.7805

A stripping experiment was performed using 400 ul of each phase

Shaking tube	Empty	With DES	With both layers	Empty	With sample	With sample and acid
979(973)	3.4027	3.8658	4.1856	7.6795	7.9011	17.5452
980(974)	3.4053	3.8667	4.1844	7.7448	7.9642	17.6235
981(975)	3.3996	3.8621	4.1793	7.7048	7.9222	17.5922

Mean disitribution ratios obtained with the malonamide in HVO100

Element	Au	Au	Cu	Cu	Cu	Au	Au	Cu
Wavelength (nm)	201.2	208.2	220.0	221.8	224.7	242.8	267.6	324.8
D Extract	14,2	14,1	0,038	0,034	0,035	13,7	14,1	0,037
% Extracted	93,4	93,4	3,7	3,3	3,4	93,2	93,4	3,5
D Strip	0.51	0.47	-	-	-	0.44	0.46	-
% Stripped	66.2	68.0	-	-	-	69.7	68.5	-

The experiment was also conducted using Aliquat 336 (5 % v/v) in 3,7-dimethyloctanol. Due to the low copper concentration in the loaded organic phase it was not possible to determine the copper distribution ratio in the stripping stage of the experiment.

Distribution ratios

Element	RJ number	Au	Au	Cu	Cu	Cu
Wavelength (nm)		201.2	208.2	220.0	221.8	224.7
D Extract 1	870	351	346	0,00477	0,00273	0,00980
D Extract 2	871	213	195	0,000298	-0,00642	0,00564
D extract 3	872	179	170	0,0129	0,00976	0,0111
D Extract (mean)		248	237	0,00599	0,00202	0,00886
% Extracted (mean)		99.6	99.6	0.59	0.20	0.88
D Strip 1	880	0.612	0.588	-	-	-
D Strip 2	881	0.607	0.592	-	-	-
D Strip 3	882	0.575	0.576	-	-	-
D Strip (mean)		0.598	0.585	-	-	-
% Stripped		62.6	63.1	-	-	-

Experiment 2 (Extraction of Au, Cu, Pb and Pd) with different concentrations of the malonamide.

A solution of metals in a mixture of sodium chloride and hydrochloric acid was made in the following way.

Condition	Gross mass of 15 ml ICP tube (g)
Empty	7.7346
After adding dilute hydrochloric acid (1 ml of 1.57 M)	8.7709
After adding a stock solution of copper, zinc, palladium and lead (1 ml)	9.7887
After adding saturated sodium chloride (1 ml)	11.0035
After adding gold / copper stock from the earing (0.1 ml)	11.0984
After adding water (7 ml)	18.2046

The dilute hydrochloric acid used was 1.57 moles per litre and was determined by back titration using our standardized sodium hydroxide and dilute nitric acid.

The copper, lead, palladium and zinc stock was made in the following way. To an empty 15 ml polyethene ICP vial was added anhydrous copper(II) chloride (10 mg), anhydrous zinc(II) chloride (10 mg), a saturated solution of lead(II) chloride in water (1 ml), Palladium stock in dilute sodium chloride (291 mg) and water (4 ml).

A series of solutions of the malonamide in HVO100 were made. Firstly a 30 % (v/v) stock of the malonamide in HVO100 was made by combining the two liquids.

Condition	Gross mass (g)
Empty	18.1380
With HVO100 diluent (8.4 ml)	24.6139
With the malonamide (3.6 ml)	27.7336

The 30 % (v/v) malonamide stock was further diluted to form 5, 10 and 20 % (v/v) solutions of the malonamide in HVO100.

Target concentration (% v/v)	Gross mass (grams)		
	Empty	With 30 % (v/v) MA	With HVO100
5	9.1524	9.9490	13.7998
10	9.1713	10.8098	13.8981
20	9.1454	12.4625	14.0150

A series of shaking vials were set up

Vial number	Gross mass (g) of shaking tube			MA concentration (% v/v)	Gross mass (g) of ICP tube		
	Empty	With aqueous layer	With both layers		Empty	With sample	With sample and acid
979	3.4010	4.1208	4.6718	30	7.743	8.1536	17.3593
980	3.4249	4.1513	4.7265	30	7.682	8.1057	17.3206

981	3.4259	4.1544	4.7322	30	7.7259	8.1258	17.3265
982	3.4339	4.1624	4.7047	20	7.6677	8.0851	17.2993
983	3.4098	4.1392	4.7048	20	7.6846	8.083	17.3013
984	3.4014	4.1316	4.7071	20	Never run leaky shaking vial		
991	3.4607	4.1866	4.7393	20	7.7316	8.1389	17.3531
985	3.4436	4.1738	4.7394	10	7.7032	8.1197	17.339
986	3.4043	4.1355	4.7030	10	7.6424	8.0547	17.2693
987	3.4418	4.1735	4.7247	10	7.6781	8.0985	17.2979
988	3.4326	4.1648	4.6970	5	7.6956	8.1044	17.3274
989	3.4368	4.1692	4.7268	5	7.689	8.0978	17.3221
990	3.4289	4.1628	4.7274	5	7.7166	8.122	17.3522
Starting solution				-	7.6724	8.0912	17.3885

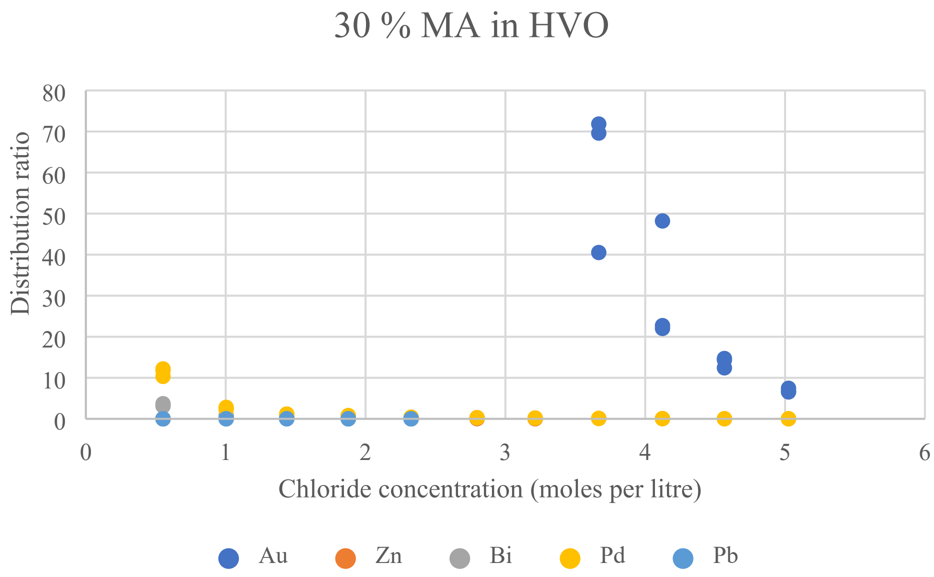
Tube	MA % (v/v)	D_{Au}	D_{Cu}	D_{Pb}	D_{Pd}	D_{Zn}
		208.20 nm	221.81 nm	220.35 nm	229.65 nm	206.20 nm
979	30	191,5008	0,011359	0,037324	22,74806	0,084812
980	30	210,8821	0,018719	0,044851	35,18361	0,105561
981	30	228,5295	0,001927	0,024334	24,49973	0,087967
982	20	156,0434	0,021885	0,026987	3,526332	0,047593
983	20	179,1806	0,025462	0,029006	4,760075	0,04884
991	20	223,7313	0,013128	0,018967	3,940221	0,033548
985	10	30,05974	0,012361	0,0102	0,185469	0,015097
986	10	30,97023	0,007927	0,004293	0,17985	0,01084
987	10	27,48337	0,024314	0,020883	0,169239	0,03115
988	5	1,609719	0,003987	-0,0033	0,010444	-0,00871
989	5	1,831482	0,019952	0,011926	0,033516	0,00899
990	5	1,901723	0,014949	0,010118	0,030129	0,006087

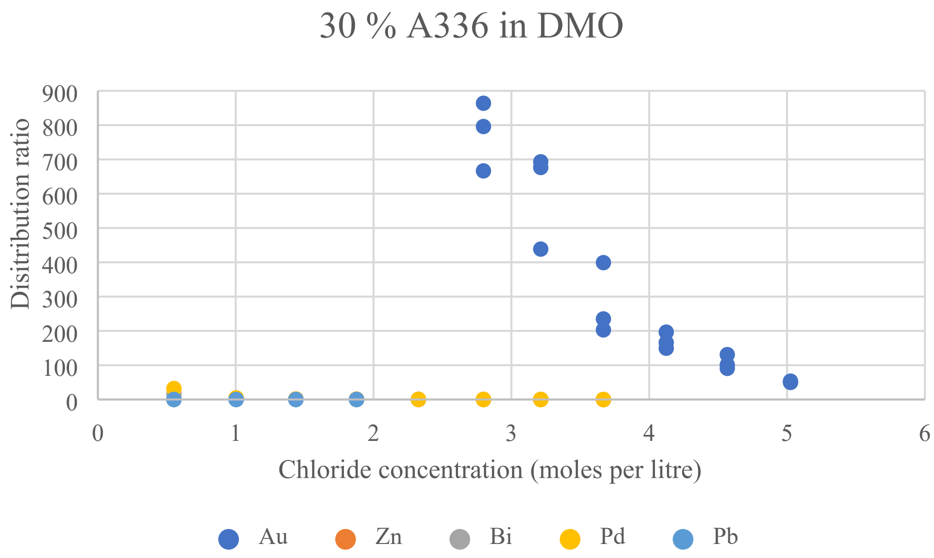
Experiment 3 (Extraction of Au, Bi, Cr, Ni, Pb, Pd and Zn)

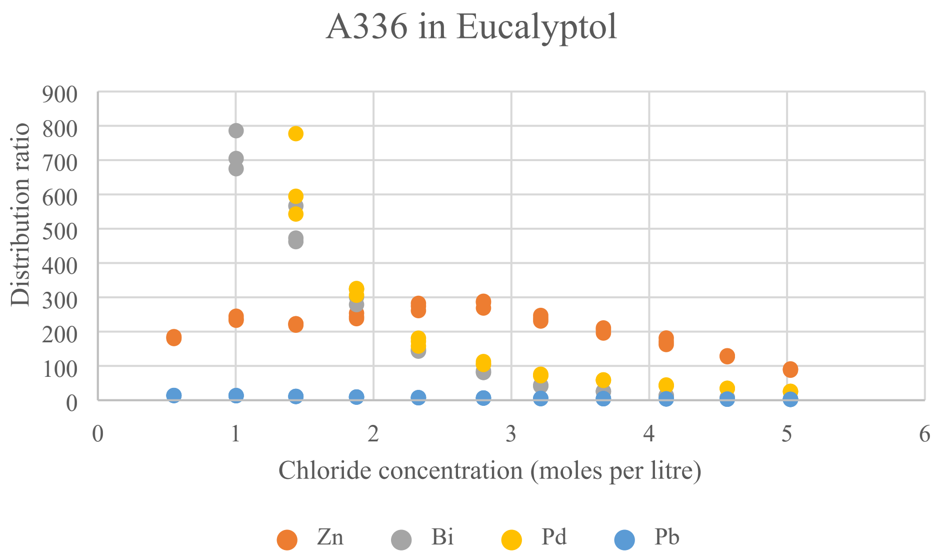
A mixed bismuth, chromium and lead stock solution was made by combining lead(II) chloride (0.6903 g), bismuth(III) oxide (0.7414 g), concentrated hydrochloric acid (66.8723 g) and water (55.0943 g). To this stock was added chromium(III) chloride hexahydrate (2.135 g).

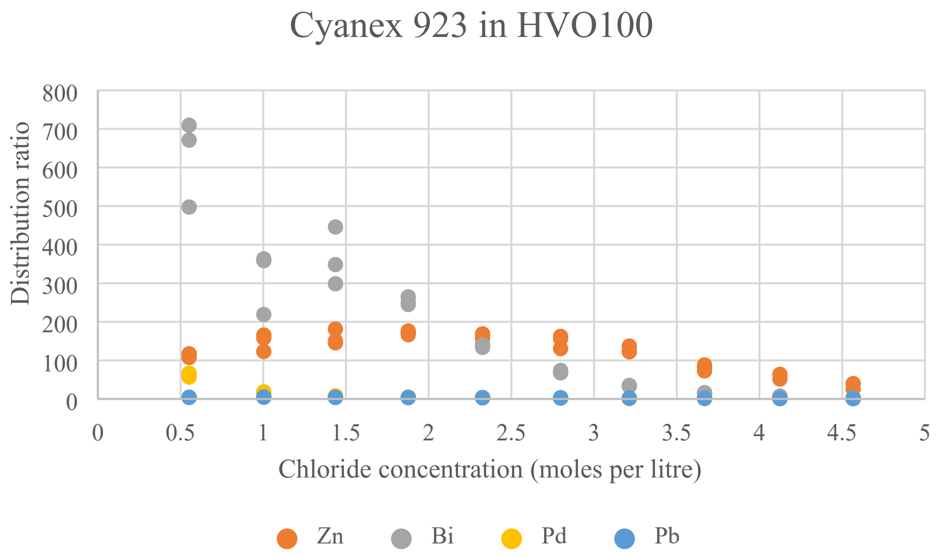
A solution of lead, bismuth and chromium(III) in different choline chloride concentrations was made for another project by adding water, choline chloride stock and the mixed bismuth, lead and chromium stock into polyethene vials (15 ml). After an initial solvent extraction experiment in 2021 the solutions were spiked with small amounts of the gold stock from the earing, a palladium stock and a mixed nickel / zinc stock before being used for the solvent extraction experiments in this paper.

The experiment can be summed up with four graphs.









None of the four extraction systems were able to extract any of the nickel or chromium present in the solutions shaken with the organic layers.

Name	***Chloride concentration***	***Density***
0 %	0,55182	1,004146
10 %	1,003183	1,013261
20 %	1,436441	1,02213
30 %	1,876601	1,031151
40 %	2,325779	1,0402
50 %	2,7975	1,049571
60 %	3,212974	1,05847
70 %	3,667736	1,067494
80 %	4,123552	1,076638
90 %	4,566412	1,085803
100 %	5,024864	1,095078

Distribution ratios obtained with 30 % malonamide in HVO100

Tube	[Cl$^-$]	D_{Au}	D_{Zn}	D_{Bi}	D_{Pd}	D_{Pb}
1015	5,024864	6,559928	0	0	0,028645	0
1016	5,024864	7,457791	0	0	0,028936	0
1017	5,024864	6,708256	0	0	0,02404	0
1018	4,566412	12,42631	0	0	0,030997	0
1019	4,566412	14,70461	0	0	0,036475	0
1020	4,566412	14,37711	0	0	0,028292	0
1021	4,123552	22,03151	0	0	0,060726	0
1022	4,123552	48,20398	0	0	0,056676	0
1023	4,123552	22,72003	0	0	0,062412	0
1024	3,667736	40,52289	0	0	0,090969	0
1025	3,667736	69,60537	0	0	0,11549	0
1026	3,667736	71,81744	0	0	0,118347	0
1027	3,212974	∞	0,046099	0	0,198309	0
1028	3,212974	∞	0,051958	0	0,197798	0
1029	3,212974	∞	0,037357	0	0,185562	0
1030	2,7975	∞	0,086668	0	0,302839	0
1031	2,7975	∞	0,067174	0	0,271227	0
1032	2,7975	∞	0,081087	0	0,282004	0
1039	2,325779	∞	0,080545	0,036124	0,345579	0,01198
1040	2,325779	∞	0,092141	0,042544	0,393779	0,013516
1041	2,325779	∞	0,090865	0,037543	0,392258	0,011253
1042	1,876601	∞	0,120783	0,099741	0,703277	0,017798
1043	1,876601	∞	0,127358	0,097674	0,683146	0,018122
1044	1,876601	∞	0,149845	0,118326	0,820506	0,018238
1045	1,436441	∞	0,152049	0,268422	1,157619	0,030804
1046	1,436441	∞	0,142985	0,251207	1,129633	0,02191
1047	1,436441	∞	0,158391	0,264877	1,165865	0,025784
1036	1,003183	∞	0,115191	0,792441	2,811493	0,02794
1037	1,003183	∞	0,103875	0,740997	2,590391	0,022908
1038	1,003183	∞	0,098307	0,683295	2,275742	0,022306
1033	0,55182	∞	0,02095	3,706007	12,17472	0,015187
1034	0,55182	∞	0,028896	3,268586	10,34677	0,018727
1035	0,55182	∞	0,022016	3,106122	11,81913	0,007704

Distribution ratios obtained with 30 % (v/v) aliquat 336 in 3,7-dimethyloctanol

	$[Cl^-]$	Au	Zn	Bi	Pd	Pb
1055	5,024864	50,85567	0	0	0	0
1056	5,024864	53,63082	0	0	0	0
1057	5,024864	49,78072	0	0	0	0
1058	4,566412	90,79408	0	0	0	0
1059	4,566412	101,0149	0	0	0	0
1060	4,566412	130,9087	0	0	0	0
1061	4,123552	196,498	0,017259	0	0,012927	0
1062	4,123552	149,4644	0,010062	0	0,005157	0
1063	4,123552	165,8665	0,029462	0	0,02135	0
1064	3,667736	202,9181	0,045336	0	0,02583	0
1065	3,667736	234,9404	0,048846	0	0,027856	0
1060n	3,667736	399,0663	0,040271	0	0,023447	0
1061n	3,212974	693,0561	0,090402	0	0,051832	0
1062n	3,212974	438,5686	0,103227	0	0,054631	0
1063n	3,212974	676,4348	0,10502	0	0,065623	0
1064n	2,7975	863,7452	0,195051	0	0,101944	0
1065n	2,7975	795,9151	0,204503	0	0,10512	0
1066n	2,7975	666,5676	0,214949	0	0,113967	0
1067	2,325779	∞	0,39697	0,05244	0,238854	0,006675
1068	2,325779	∞	0,394643	0,05117	0,236695	0,002199
1069	2,325779	∞	0,391141	0,040195	0,228948	0
1070	1,876601	∞	0,725006	0,154093	0,536281	0,022712
1071	1,876601	∞	0,720048	0,145024	0,526447	0,013713
1072	1,876601	∞	0,713659	0,125478	0,522041	0,012168
1073	1,436441	∞	1,029616	0,462842	1,238951	0,038423
1074	1,436441	∞	1,128116	0,542682	1,349631	0,040884
1075	1,436441	∞	1,129882	0,524645	1,343494	0,051947
1076	1,003183	∞	1,152037	2,255974	4,63223	0,065023
1077	1,003183	∞	1,129926	2,240392	4,522276	0,053773
1078	1,003183	∞	1,139009	2,271526	4,571619	0,0627
1079	0,55182	∞	0,532385	16,04512	31,97774	0,06526
1080	0,55182	∞	0,531753	15,90277	31,57221	0,065635
1081	0,55182	∞	0,527011	15,21728	31,47428	0,061925

Distribution ratios obtained with 30 % (v/v) cyanex 923 in HVO100

Tube number	[Cl$^-$]	Au 201.200 (Aqueous-Axial-iFR)	Zn 202.548 (Aqueous-Axial-iFR)	Bi 223.061 (Aqueous-Axial-iFR)	Pd 340.458 (Aqueous-Axial-iFR)	Pb 216.999 (Aqueous-Axial-iFR)

1178	5,024864	3rd Phase	3rd Phase	3rd Phase	3rd Phase	3rd Phase
1179	5,024864	3rd Phase	3rd Phase	3rd Phase	3rd Phase	3rd Phase
1180	5,024864	3rd Phase	3rd Phase	3rd Phase	3rd Phase	3rd Phase
1181	4,566412	∞	39,5739	2,858317	0,897879	1,116795
1182	4,566412	∞	39,70805	2,842274	0,889947	1,096712
1183	4,566412	∞	26,3785	3,129292	0,787782	0,981814
1184	4,123552	∞	63,87833	7,176091	1,161244	1,472259
1185	4,123552	∞	51,86924	7,075992	1,12526	1,447601
1186	4,123552	∞	63,29328	7,247587	1,172408	1,468838
1187	3,667736	∞	88,17941	16,2514	1,450083	1,861334
1188	3,667736	∞	72,90818	15,62771	1,385564	1,81034
1189	3,667736	∞	82,96475	16,06594	1,443768	1,834636
1190	3,212974	∞	122,4172	33,42517	1,624635	2,171514
1191	3,212974	∞	137,2191	35,29198	1,699891	2,283924
1192	3,212974	∞	123,1606	34,04189	1,650206	2,231606
1193	2,7975	∞	130,7102	69,4471	2,814711	3,01121
1194	2,7975	∞	162,2805	74,04229	2,896116	3,07388
1195	2,7975	∞	156,0628	67,76614	2,436777	2,679046
1196	2,325779	∞	156,0109	133,7143	3,621949	3,503935
1197	2,325779	∞	168,7429	140,5645	3,647838	3,498535
1198	2,325779	∞	165,9085	137,6602	3,226996	3,168845
1199	1,876601	∞	176,2722	264,8988	4,615159	3,804332
1200	1,876601	∞	172,1373	244,9416	4,642346	3,704243
1201	1,876601	∞	166,7349	251,1252	4,863608	3,920874
1202	1,436441	∞	150,4945	∞	7,981898	4,227086
1203	1,436441	∞	145,6484	∞	7,772048	4,238601
1204	1,436441	∞	181,1565	∞	7,842497	4,28742
1208	1,003183	∞	165,7408	∞	17,37423	4,842886
1209	1,003183	∞	122,983	∞	17,52085	4,915064
1210	1,003183	∞	158,1199	∞	18,62088	4,992349
1211	0,55182	∞	107,7271	∞	56,87427	4,137027
1212	0,55182	∞	117,1514	∞	66,6469	4,388897
1213	0,55182	∞	116,1975	∞	66,24174	4,424923

Distribution ratios obtained with 30 % aliquat 336 in eucalyptol

Tube number	$[Cl^-]$	Au 201.200 (Aqueous-Axial-iFR)	Zn 202.548 (Aqueous-Axial-iFR)	Bi 223.061 (Aqueous-Axial-iFR)	Pd 340.458 (Aqueous-Axial-iFR)	Pb 216.999 (Aqueous-Axial-iFR)
1082	5,024864	∞	87,50441	3,070456	24,69335	2,398661
1083	5,024864	∞	91,3106	3,181704	25,90109	2,473515
1084	5,024864	∞	89,96649	3,412711	25,75485	2,441076
1085	4,566412	∞	129,6087	7,059899	34,43492	3,151142
1086	4,566412	∞	126,8174	7,114511	33,98085	3,054425
1087	4,566412	∞	128,9628	7,263925	34,89183	3,129644
1088	4,123552	∞	181,3856	14,08119	44,43152	3,953988
1089	4,123552	∞	170,9618	13,57756	43,00365	3,851854
1090	4,123552	∞	162,4691	13,0886	42,08161	3,755446
1091	3,667736	∞	210,7771	24,68926	59,37672	4,555556
1092	3,667736	∞	195,871	26,4322	58,81876	4,461647
1093	3,667736	∞	205,5587	25,98213	57,70056	4,550481
1094	3,212974	∞	238,5194	41,87083	72,33423	4,901458
1095	3,212974	∞	247,2134	44,30761	75,70954	5,291833
1096	3,212974	∞	230,8738	40,92813	71,36273	4,691424
1097	2,7975	∞	268,766	80,89024	106,6334	6,224877
1098	2,7975	∞	288,4938	85,97609	112,725	6,443025
1099	2,7975	∞	284,9496	81,16381	104,2031	6,448864
1100	2,325779	∞	274,4219	144,9756	171,7108	7,606463
1101	2,325779	∞	282,4794	143,0693	180,9661	7,479378
1102	2,325779	∞	261,2948	148,9658	157,8397	7,300477
1103	1,876601	∞	253,6357	278,7964	325,7026	9,383599
1104	1,876601	∞	237,8573	300,7802	306,1739	9,171335
1105	1,876601	∞	243,5966	324,1278	323,4845	9,298149
1106	1,436441	∞	222,6911	566,6268	542,8843	10,99805
1107	1,436441	∞	222,9976	462,3909	777,2019	11,19569
1108	1,436441	∞	218,8573	472,7891	594,612	10,9541
1109	1,003183	∞	233,168	704,7896	∞	13,31547
1110	1,003183	∞	236,8269	674,9904	∞	13,57794
1111	1,003183	∞	244,9216	785,859	∞	13,45315
1112	0,55182	∞	179,8368	∞	∞	13,57717
1113	0,55182	∞	182,7206	∞	∞	13,8215
1114	0,55182	∞	185,3502	∞	∞	13,88292

Experiment 4 (Effect of acid concentration on the extraction)

Sodium chloride was dissolved in water, samples of the resulting solution were titrated using silver nitrate (0.1 M) using chromate as the indicator. The end point was judged by eye as when a stable red colouration was seen in the flask into which silver nitrate (0.10011 moles per litre) was added. The same general method was used as was used to determine the concentration of the choline chloride solution.

Titration run	1	2	3
Mass of sodium chloride solution used (g)	1.1283	1.1415	1.1503
Volume of silver nitrate solution used (ml)	33.35	33.7	33.9
Sodium chloride concentration (Mole dm^{-3})	3.339	3.374	3.394

Average of the three concentrations is 3.37 moles per litre. Standard deviation 0.029 moles per litre.

Due to the high acidity of the hydrochloric acid stock (*crica* 3 M) it was impossible to use chromate as the indicator. To determine the concentration of the hydrochloric acid a sample was placed in a conical flask to which a known excess of sodium hydroxide solution was added. The resulting alkaline mixture was spiked with bromothymol blue solution before being titrated to a yellow end point with dilute nitric acid.

Titration run	1	2	3
Volume of *circa* 3 M acid (ml)	0.5	0.5	0.5
Volume of sodium hydroxide stock (ml)	20	20	20
Volume of dilute nitric acid added	8.8	8.6	8.7
Concentration of acid (moles per litre)	2.95	2.97	2.96

Average of the three determinations is 2.96 moles per litre. Standard deviation is 0.0109 moles per litre.

Solution name	Volume of sodium chloride stock	Volume of hydrochloric acid stock	Volume of water	Volume of gold / copper stock	Volume of COLABATS metal stock
0% Acid	5,93	0	3,465282	0.1	0.5
10% Acid	5,34	0,675676	3,383078	0.1	0.5
20% Acid	4,75	1,351351	3,300874	0.1	0.5
30% Acid	4,15	2,027027	3,21867	0.1	0.5
40% Acid	3,56	2,702703	3,136466	0.1	0.5
50% Acid	2,97	3,378378	3,054263	0.1	0.5
60% Acid	2,37	4,054054	2,972059	0.1	0.5
70% Acid	1,78	4,72973	2,889855	0.1	0.5
80% Acid	1,19	5,405405	2,807651	0.1	0.5
90% Acid	0,59	6,081081	2,725447	0.1	0.5
100% Acid	0	6,756757	2,643243	0.1	0.5

Experiment 5 (Metal contamination of HVO100)

Superpure nitric acid was added to MQ grade water in a polyethene bottle (2 L) which had been rinsed many times with super pure nitric acid and had been used exclusively by Mark Foreman for the preparation and storage of super pure nitric acid for 15 years. The concentration of the nitric acid was 1 mole per litre.

Small aliquats of this super pure nitric acid (800 μl) were placed in glass shaking vials, to these vials was added HVO100 fuel (1.6 ml) either before or after standing over alumina. The vials were capped with polyethene caps before being shaken by hand (two minutes). After centrifugation (4000 rpm for 10 minutes) the lower layers were sampled by removing 500 μl by pipette. There were then diluted in 15 ml polyethene vials with 1 M hydrochloric acid containing 0.5 % oxalic acid made by dissolving the acids in MQ water.

The diluted samples of acid shaken with HVO100 were examined with a ICPOES machine. The machine was set up to record the intensities of ultraviolet light associated with many elements.[A] These elements included all the non radioactive alkaline earth metals, lithium, sodium, potassium, first row transition metals, boron, aluminium, silicon, phosphorus, lead, cadmium, zinc, mercury, lanthanum, yttrium and neodymium.

Element	Untreated HVO100	HVO treated with alumina
Boron	**Yes**	**Yes**
Aluminium	**Yes**	**Yes**
Silicon	**Yes**	**Yes**
Phosphorus	No	No
Tin	No	No
Lead	No	No
Bismuth	No	No

Element	Untreated HVO100	HVO treated with alumina
Lithium	No	No
Sodium	**Yes**	**Yes**
Potassium	No	No
Beryllium	No	No
Magnesium	No	No
Calcium	**Yes**	**Yes**
Strontium	No	No
Barium	No	No

Element	Untreated HVO100	HVO treated with alumina
Scandium		
Titanium	No	No
Vanadium	No	No

[A] Aluminim, phosphorus, boron, lead, calcium, mercury, silicon, tin, cobalt, zinc, magnesium, copper, cadmium, strontium, nickel, bismuth, barium, lanthanum, scandium, iron, beryllium, ruthenium, rhodium, manganese, chromium, vanadium, titanium, lithium, yttrium, sodium, neodymium, potassium,

Chromium	No	No
Manganese	No	No
Iron	No	No
Cobalt	No	No
Nickel	No	No
Copper	No	No
Zinc	No	No
Yttrium	No	No
Lanthanum	No	No
Neodymium	No	No
Cadmium	No	No
Mercury	No	No

Experiment 6 (Solubility of water in HVO100)

Diluents (2 ml) were shaken with a solution of tritium as tritiated water combined with normal water (0.2 ml) in shaking tubes. The samples were allowed to stand (90 minutes) to allow the two liquid layers to separate. The upper layer was sampled and then examined with liquid scintillation counting. For comparison the tritiated water mixed with normal water was examined with liquid scintillation counting.

The counting time was set to 3600 seconds (one hour) per tube, but the machine was set up so that if a tube reached 10000 counts that the counting time would be terminated early to save time.

Sample	Volume (ml)	Crude counts per minute	Corrected counts per minute	Water content (ppm)
Blank	-	6.1	-	-
Blank	-	5.7	-	-
Solvent 70	0.5	19.4	13.5	35.84864
Solvent 70	0.5	12.4	6.5	17.26045
Solvent 70	0.5	20.3	14.4	38.23854
HVO100	0.5	19.8	13.9	36.91082
HVO100	0.5	18.5	12.6	33.45873
HVO100	0.5	18	12.1	32.131
Eucalyptol	0.5	2116.6	2110.7	5604.868
Eucalyptol	0.5	2082.3	2076.4	5513.786
Eucalyptol	0.5	2124	2118.1	5624.518
Solvesso 150ND	0.5	130.9	125	331.9318
Solvesso 150ND	0.5	130	124.1	329.5419
Solvesso 150ND	0.5	192.6	186.7	495.7733
Starting solution	0.2	151547.9	151542	100 %
Starting solution	0.2	149730.6	149724.7	100 %

Initial gold extraction experiment using pure diluents (RJ)

Sodium chloride concentration (moles dm^{-3})	Eucalyptol	3,7-Dimethyloctanol
0.61	106.63	0.27
0.61	77.98	0.25
0.61	90.47	0.28
1.22	82.58	0.31
1.22	0.22	0.31
1.22	69.18	0.23
1.83	4.83	0.29
1.83	0.87	0.35
1.83	0.61	0.30
2.44	4.71	0.33
2.44	1.70	0.23
2.44	1.50	0.23
3.05	1.58	0.54
3.05	2.31	0.39
3.05	1.92	0.49
3.67	0.67	0.65
3.67	0.41	0.62
3.67	0.38	0.29
4.28	0.79	0.73
4.28	0.87	0.97
4.28	1.49	0.56
4.89	0.63	0.70
4.89	1.30	0.87
4.89	0.73	0.89
5.50	1.63	1.44
5.50	1.01	1.07
5.50	3.58	1.45
6.11	4.09	1.42
6.11	1.58	1.10
6.11	2.56	1.09

Gold extraction by dilute solutions of aliquat 336 in dimethyl octanol from sodium chloride solutions.

	Gold distribution ratio (D_{Au})		
Sodium chloride concentration (moles dm^{-3})	Aliquat 336 concentration % (v/v)		
	5	2.5	1
2.44	161.30	79.75	70.30
2.44	139.05	75.69	37.51
2.44	76.83	58.73	82.36
3.67	70.86	49.49	47.64
3.67	92.02	49.49	44.05
3.67	62.04	47.60	63.59
4.89	59.89	44.24	34.00
4.89	88.83	52.69	42.40
4.89	85.26	53.65	45.15
6.11	70.80	40.29	58.99
6.11	78.31	68.93	36.73
6.11	74.10	59.36	35.48

Distribution ratios obtained with a 1 % solution of aliquat 336 in dimethyloctanol when the main electrolyte was choline chloride.

Choline chloride concentration (moles per litre)	D_{Au}
0,61	40,58
0,61	**56,27**
0,61	40,87
1,23	**15,46**
1,23	170,8
1,23	220,1
1,84	10,54
1,84	11,85
1,84	10,66
2,45	5,46
2,45	7,43
2,45	10,44
3,07	2,824
3,07	2,766
3,07	3,116
3,68	1,959
3,68	1,834
3,68	1,724
4,29	1,158
4,29	0,9292
4,29	1,069
4,91	0,4822
4,91	0,4677
4,91	0,5083
5,52	0,2523
5,52	0,2535
5,52	0,2256
6,13	**0,06013**
6,13	0,1193
6,13	**0,05315**

Kinetics of the extraction of gold

The organic phase was a 10 % (v/v) solution of the *N,N,N′,N′-tetrakis* (2-ethylhexyl) malonamide in HVO100. This was shaken with a solution of gold(III) and copper(II) in a mixture of hydrochloric acid and sodium chloride solution. The mass of the 50 ml polyethene vial used to make up the starting solutions for the extraction experiments is summarised in the following table.

Condition	Mass (g)
Empty	
With hydrochloric acid (2.96 M)	10.5451
With sodium chloride stock (3.37 M)	21.8215
With water	31.8793
With gold stock from scrap gold (200 μl)	32.1750

Experimental results

Tube number	Time (minutes)	Au 208,209 (Aqueous-Axial-iFR)	Cu 221,810 (Aqueous-Axial-iFR)	Cu 224,700 (Aqueous-Axial-iFR)	Au 242,795 (Aqueous-Axial-iFR)	Au 267,595 (Aqueous-Axial-iFR)	Cu 324,754 (Aqueous-Axial-iFR)
1815	6	166.725	0.003	-0.003	164.290	168.334	-0.015
1816	6	127.791	-0.008	-0.010	126.184	125.616	-0.011
1817	6	123.401	-0.014	-0.016	125.022	125.654	-0.015
1818	32	68.157	0.001	0.001	67.326	67.975	-0.007
1819	32	63.934	-0.005	-0.005	62.494	63.576	-0.002
1820	32	62.737	-0.013	-0.013	62.134	63.172	-0.008
1824	76	42.525	0.002	0.008	42.361	42.973	0.005
1825	76	40.853	0.009	0.014	40.148	40.414	0.006
1826	76	43.008	0.004	0.008	42.675	43.173	-0.002
1821	308	34.238	0.017	0.021	33.370	33.997	0.014
1822	308	30.515	0.027	0.031	29.733	30.299	0.022
1823	308	31.956	0.015	0.022	31.346	32.123	0.018
1827	1676	24.547	0.017	0.023	23.944	24.346	0.014
1828	1676	20.822	0.016	0.019	20.355	20.682	0.009
1829	1676	22.815	0.018	0.022	22.469	22.893	0.022

Effect of acid concentration on the gold extraction

Sodium chloride and hydrochloric acid were dissolved in water to form the stock solutions. These were titrated with silver chloride (using a chromate indicator) and in an acid / base titration using dilute sodium hydroxide (back titration with dilute nitric acid).

The sodium chloride concentration was 3.37 moles per litre while the hydrochloric acid stock was 2.96 moles per litre. Using these stock solutions a series of aqueous starting solutions were made. In the following table the amounts of the liquids required are displayed.

The intent was to keep the total chloride concentration at 2 moles per litre. The contribution of the metal stocks to the chloride content of the final solutions was ignored.

Acid fraction	Sodium chloride volume	Acid volume	Gold stock	Colabats stock	Water
0	5.934718	0	0.1	0.5	3.465282
0.1	5.341246	0.675676	0.1	0.5	3.383078
0.2	4.747774	1.351351	0.1	0.5	3.300874
0.3	4.154303	2.027027	0.1	0.5	3.21867
0.4	3.560831	2.702703	0.1	0.5	3.136466
0.5	2.967359	3.378378	0.1	0.5	3.054263
0.6	2.373887	4.054054	0.1	0.5	2.972059
0.7	1.780415	4.72973	0.1	0.5	2.889855
0.8	1.186944	5.405405	0.1	0.5	2.807651
0.9	0.593472	6.081081	0.1	0.5	2.725447
1	0	6.756757	0.1	0.5	2.643243

Acid concentration	Gold distribution ratio				
(moles per litre)	197,819 nm	201,200 nm	208,209 nm	242,795 nm	267,595 nm
0	8.48	9.58	9.49	9.54	9.54
0	9.76	11.30	11.25	11.14	11.20
0	9.68	10.72	10.78	10.69	10.63
2	45.94	87.97	85.57	85.70	83.25
2	44.54	79.49	81.35	81.37	78.33
2	49.05	90.75	86.14	87.42	84.20
0.2	23.33	28.26	27.84	27.52	26.98
0.2	21.71	26.33	25.82	25.82	25.53
0.2	21.82	26.05	25.61	25.52	24.93
0.4	21.84	25.90	26.16	25.88	25.56
0.4	23.81	28.76	28.72	28.63	28.17
0.4	20.19	23.41	23.53	23.26	22.97
0.6	22.83	27.96	27.85	27.57	27.42
0.6	26.21	31.90	31.74	31.49	31.24
0.6	24.91	31.66	32.19	31.59	31.36
0.8	32.97	43.68	43.89	43.77	42.74
0.8	34.66	47.20	46.50	46.35	45.29
0.8	34.26	46.27	46.72	46.68	45.51

1.0	33.31	51.27	50.36	50.30	49.75
1.0	30.16	45.47	45.08	44.55	44.52
1.0	44.73	70.89	69.53	71.19	69.49
1.2	32.42	44.12	43.24	43.27	42.90
1.2	36.63	55.74	55.42	55.49	54.55
1.2	37.17	50.56	49.45	50.07	49.61
1.4	39.65	63.30	63.67	64.15	62.97
1.4	40.26	58.89	57.53	57.74	56.98
1.4	43.38	66.03	64.92	64.86	63.68
1.6	42.58	70.58	66.63	66.95	65.33
1.6	43.23	61.65	60.28	60.72	59.54
1.6	44.51	70.72	68.51	68.91	67.41
1.8	23.82	29.30	28.96	28.55	28.72
1.8	25.61	32.84	33.06	32.41	32.41
1.8	24.84	32.16	32.43	31.64	31.79

The solvent extraction experiment was conducted with MIBK using the 2 mole per litre acid and the 0 mole per litre acid. With no acid the gold disitribution ratio was over 100 while with the 2 mole per litre acid it was greater than 1000.

Extraction of gold and other elements with other organic reagents from hydrochloric acid.

A solution of metals was formed by adding aqueous solutions to a 50 ml polyethene vial.

Condition	Mass (g)
Empty	14.4066
With 600 μl palladium(II) (18.4 g L^{-1}) in chloride media	15.0317
With 375 μl nickel / zinc stock (each metal at 32 g L^{-1} as chlorides)	15.4452
With 1500 μl COLABATS stock (Al, Cd, Co, Fe, La, Ce, Pr, Nd, Zn at 8000 ppm)	17.1385
With 200 μl gold / copper stock from scrap gold	17.4072
With 2.96 M hydrochloric acid (20.27 ml)	39.0116
With water (7 ml)	46.2694

Equal volumes of the aqueous phase and a series of organic layers were shaken for two hours at 25 ^{o}C before centrifugation and sampling of the aqueous layer.

The organic phases were 10 % TEHMA (*N,N,N',N'-tetrakis*-(2-ethylhexyl) malonamide in HVO100, pure tributylphosphate, acetophenone, pure tetrabutyl malonamide (TBMA), L-menthone, 30 % DEHBA (Di-2-ethylhexyl butamide) in HVO100, 30 % tributyl phosphate in HVO100, 10 % tetrabutyl malonamide in HVO100, 30 % tetrabutyl malonamide in HVO100 and 30 % DEHPA (Di-(2-ethylhexyl) hydrogen phosphate) in HVO100.

The solutions of TBMA in HVO100 formed intractable third phases with the aqueous layer. The acetophenone was very difficult to sample (both layers have similar densities).

Prediction of the performance of a process for the decontamination of ^{210}Pb polluted gold.

Imagine that we were to start with gold with a level of ^{210}Pb which is one million times higher than the acceptable limit.

If the extraction was to occur using 30 % malonamide using HVO100 as a diluent using an aqueous phase which is operating at the chloride concentration which causes the lead distribution ratio to be 0.03, under these conditions the distribution ratio of gold will be far above 100, so we can assume that a total extraction of gold will occur. We assume that we have a later stage which recovers all the gold and lead out of the loaded organic phase at the end.

With one stage of extraction then we will have 2.9 % of the lead extracted, the gold coming out of this stage will now be 29000 times too contaminated for use. If we pass the organic phase bearing the gold into a counter current battery of mixer settlers or some other contactors then it will be possible to clean up the gold.

With three stages of counter current scrubbing (back extraction of the unwanted element) then the three scrub stages will remove 99.9976 % of the lead which enters the scrub stage. The gold is now at 66 % of the limit.

If we wanted to be very sure an additional scrub stage could be added to the process, with four scrub stages the scrub section will remove 99.9999 % of the lead which enters it. As a result the gold would be then only at 2 % of the limit.

Even if we assume that a total extraction of the ^{210}Bi occurs in the first section then if we make a pessimistic assumption that the bismuth disitribution ratio in the scrub section is 0.5. Then with three stages we will remove 93 % of the bismuth in the scrub section.

The main threat posed by ^{210}Pb contamination in jewellery is bremsstrahlung (braking radiation) generated by the interactions of the high energy beta particles from ^{210}Bi with the gold metal. If we assume that all the lead is removed from the gold and 7 % of the bismuth remains (three scrub stages) then the dose rate to the skin in contact with gold jewellery fabricated on the day of the separation will be equivalent to that after allowing the untreated contaminated gold to stand for 84.4 years.

If the separated gold was allowed to stand for 81 days then the bremsstrahlung emission would be one million times lower than the original gold.

If we moved to four scrub stages then 3.22 % of the bismuth would remain in the gold, this only reduces the cooling time after the separation to about 76 days.

If we change the scrub stage to use a higher concentration of chloride where the bismuth distribution ratio will now be 0.036 then with three scrub stages the ^{210}Bi level will only be 45 times the limit after the scrub (99.9955 % of the bismuth scrubbed out). This will require a further cooling time of 28 days.

With four scrub stages then the cooling time after the separation will be 3.5 days before the ^{210}Bi level in the gold is sufficiently low.

Note that as no stable isotope of polonium exists we have not measured the distribution ratios of polonium so we can not predict how this element will behave in the process. As the physical half life of ^{210}Po is 140 days, then storage of the gold after removal of the lead for 7.7 years would ensure that the polonium contamination in the gold will be one million times lower. While 439 years is a very long time for gold to be kept in a secure store it may be reasonable to store gold for eight years.

For comparison the gold which is one million times as radioactive as the limit a cooling time of 439 years would be required if no chemical separation is used.

Radiological health and safety justification of the use of tritium in the work.

The use of tritium is a single one off experiment which is not intended to be repeated by the readers if they are using HVO100 as a diluent. It is an experiment which is used at Chalmers as an alternative to the Karl Fisher titration. As the use of X-ray generators for X-ray Diffraction (XRD) and X-ray fluorescence (XRF) is considered an acceptable radiation practise in papers published in a range of RSC journals including green chemistry. It is reasonable to compare the use of tritium to XRD equipment.

Let us assume that we use a staggering 100 MBq of tritium for the work, in real life we will aim to work with much less tritium.

If we consider the worst possible accidents in a radioactivity area with tritium. The IAEA have reasoned that the smallest creditable amount of tritium which when dispersed is able to cause an injury which leads to either death or a permanent effect which lowers a person's quality of life is 2000 TBq.

They consider a series of scenarios, one or more of these is able to cause either death of a serious injury. It is not in the public interest to attempt to deduce which of the three is the one of greatest concern.

- Inhalation of one thousandth of the radioactive source, this would be inhaling 2 TBq of tritium.
- Swallowing (ingestion) of 0.001 % (20 GBq) of the tritium.
- Skin contamination with 1 % of the source (20 TBq of tritium) spread over 1 m^2 of skin

Based on these values it can be concluded that if the world's worst radiochemist was to do the experiment using 100 MBq of tritium (1 MBq of tritium per shaking tube, and to measure 100 solubilities of water) using our method while working in a poorly ventilated room on the open bench then they would not be able to have an intake which would result in death or permanent disability. This behaviour would result however in ejection from nuclear chemistry at Chalmers. We imagine that the national nuclear / radiation regulatory body would be dismayed at such conduct and would take action.

The annual limit of intake (ALI) for inhalation and swallowing tritium is 1.1 GBq. So if our hypothetical "worst radiochemist in the world" takes leave of their senses and swallows the entire 100 MBq of tritium. Then they would have an intake which is less than 10 % of the annual intake limit.

The IAEA classifies radioactive sources into five broad classes depending on their ability to cause death / injury when mishandled. Based on the advice which the IAEA give on the classification of radioactive sources, the 100 MBq of trtium is a category five source. This is a source which is unable to cause death or injury in a creditable accident.

If we compare the use of tritiated water with the use of X-ray diffraction equipment, many X-ray diffraction sets use working beams which are able to cause localised injuries which are comparable with those caused by the mishandling of high activity sources.

Table of category one to five sources as defined by the IAEA.

Category	Fatal exposure	Lasting injury	Typical example	A/D range
1	Within minutes	Within minutes	Food irradiator source	>1000
2	Within hours to days	Within minutes to hours	Industrial radiography source	10 to 1000
3	Even an exposure of days to weeks is unlikely to be fatal	Could cause injury after an exposure which lasts hours	Oil well logging source	1 to 10
4	Not likely to kill	Temporary injury after exposure of weeks	Source in nuclear gauge	0.01 to 1
5	Not able to kill	Unable to injure	Calibration source	< 0.01

My assessment of a 2 kW DC input copper anode X-ray tube based on the scenario that a person accidently places their hand in a working beam is that the X-ray source could in seconds deliver a dose which causes an injury to the skin. For skin effects I would rate the XRD source as category two but for effects deep in the torso I would rate it as being below category two.

This places a typical diffraction set at about the same level as the ^{137}Cs source which was stolen from a radioactive waste store in Tammiku (Estonia) in 1994. This source could be safely manipulated without shielding using a 1 m long pair of tongs if the worker is able to work quickly. The Tammiku source contained between 150 GBq and 7.4 TBq of ^{137}Cs (IAEA D value is 100 GBq). This places the source in either in category two or three

As a result the gamma dose rate at one meter (Between 15.3 and 764 mSv hr^{-1} at 1 m) will be such that a classified worker[B] could manipulate the source with a 1 m long pair of tongs. At the upper activity limit the worker would need to complete the task in less than 90 seconds to avoid reaching their annual exposure limit (20 mSv). While at the lower activity limit for the source the worker would have more than one hour to perform the task.

The radiation field from the Tammiku source at 20 cm would be weaker than what would be expected for a unmonochromated working beam for an X-ray diffraction machine. We would expect the XRD machine's source to be able to cause a small radiation burn after less than one minute of exposure, but due to the low photon energy (less than 50 keV) we would expect that the XRD source would be able to deliver a life-threatening dose to the vital organs inside the torso.

The Annual Limit of Intake (ALI) for tritium for a classified worker (nuclear worker with the medical clearance needed for the highest radiation exposures allowed by law in either the UK or the EU) is high. In Sweden the ALI is set at 1100 MBq for both inhalation and oral exposure to tritium. The 100

[B] Classified worker is the UK term for a radiation worker who is allowed to be exposed up to the annual limit for workers, these are workers over the age of 18 who are subject to medical supervision (regular blood tests and medical examinations). A biological basis exists for limiting the radiation exposure of children and young people, as a result below the age of 16 radiation work is forbidden. In Sweden and other EU countries such persons are described as "Category A radiation workers". Currently the exposure limits for classified workers (Category A workers) are whole body, lens of eye, skin and hands / feet are 20, 20, 500 and 500 mSv per year (Swedish implementation of the regulations is SFS 2018:506). Category B workers (non classified radiation workers) are limited to 6, 6, 150 and 150 mSv per year of exposure to their whole body, lens of eye, skin and hands / feet.

MBq does not come near to the ALI, so even in the world's worst radiochemist was to swallow all of the 100 MBq tritium stock they would not exceed the ALI.

For workers oral exposure to tritium as tritiated water is considered by the IRCP to cause the person to have an effective dose which is proportional to the tritium intake.

42 pSv Bq^{-1}, so if a worker was to have an intake of 1 MBq of tritium then they would commit to an effective dose of 42 microSv. Thus if the intake was 100 MBq then the committed effective dose would be 4.2 mSv. This is 21 % of the yearly limit for occupational exposure of a classified worker.

For inhalation of tritium as tritiated water the dose coefficient is 18 pSv Bq^{-1} so exposure via the lungs is less harmful.

Derivation of equations used to model the gold extraction.

If we assume that the only forms of gold present in the aqueous phase are the neutral complex ($AuCl_3$) and the anionic complex ($AuCl_4^-$) then we can write this equation for the fraction of the gold which is in the form of the anionic complex.

$$\frac{\left[AuCl_4^-\right]}{\left[AuCl_3\right]+\left[AuCl_4^-\right]}=\frac{\left(\dfrac{k_4[Cl^-]f_{Cl^-}[AuCl_3]f_{AuCl_3}}{f_{AuCl_4^-}}\right)}{\left[AuCl_3\right]+\left(\dfrac{k_4[Cl^-]f_{Cl^-}[AuCl_3]f_{AuCl_3}}{f_{AuCl_4^-}}\right)}$$

Divide the right hand side by [$AuCl_3$], this then gives us.

$$\frac{\left[AuCl_4^-\right]}{\left[AuCl_3\right]+\left[AuCl_4^-\right]}=\frac{\left(\dfrac{k_4[Cl^-]f_{Cl^-}f_{AuCl_3}}{f_{AuCl_4^-}}\right)}{1+\left(\dfrac{k_4[Cl^-]f_{Cl^-}f_{AuCl_3}}{f_{AuCl_4^-}}\right)}$$

If the right hand term in the denominator on the right hand side is far greater than 1, then we can write,

$$\frac{\left[AuCl_4^-\right]}{\left[AuCl_3\right]+\left[AuCl_4^-\right]}=\frac{\left(\dfrac{k_4[Cl^-]f_{Cl^-}f_{AuCl_3}}{f_{AuCl_4^-}}\right)}{\left(\dfrac{k_4[Cl^-]f_{Cl^-}f_{AuCl_3}}{f_{AuCl_4^-}}\right)}=1$$

Which means that all of the gold is present in the anionic tetrachloro complex. This will make the later equations more simple. Now if we have an equation for the extraction of the anion by the aliquat 336 (liquid anion exchanger) which defines the extraction constant.

$$k_{ex}=\frac{f_{{AuCl_4^-}_{org}}\,f_{Cl^-}[Cl^-]\left[AuCl_4^-\right]_{org}}{f_{Cl^-_{Org}}\,f_{AuCl_4^-}[Cl^-]_{org}\left[AuCl_4^-\right]}$$

We can rearrange the equation to give us the reciprocal of the gold disitribution ratio

$$\frac{\left[AuCl_4^-\right]}{\left[AuCl_4^-\right]_{org}}=\frac{f_{{AuCl_4^-}_{org}}\,f_{Cl^-}[Cl^-]}{k_{ex}f_{Cl^-_{Org}}\,f_{AuCl_4^-}[Cl^-]_{org}}$$

Turn everything upside down to give us

$$D_{Au} = \frac{\left[AuCl_4^-\right]_{org}}{\left[AuCl_4^-\right]} = \frac{k_{ex} f_{{Cl_{Org}}^-} f_{AuCl_4^-} [Cl^-]_{org}}{f_{{AuCl_4}_{org}^-} f_{Cl^-} [Cl^-]}$$

Now we introduce a new constant U which allows us to put the organic layer activity functions and the concentration of the chloride anions in the organic phase into a single constant.

$$D_{Au} = \frac{k_{ex} U f_{AuCl_4^-}}{f_{Cl^-} [Cl^-]}$$

If we use a Pitzer equation with two terms in the polynomial as written below for the activity fuction

$$\log f = \frac{-z^2 S\sqrt{I}}{1 + \left(\frac{3\sqrt{I}}{2}\right)} + A\left[Ch^+\right] + B\left[Ch^+\right]^2$$

Now we can write

$$f = 10^{\left(A\left[Ch^+\right] + B\left[Ch^+\right]^2 - \frac{z^2 S\sqrt{I}}{1 + \left(\frac{3\sqrt{I}}{2}\right)}\right)}$$

Then as we are interested in one activity function divided by another we can write.

$$\frac{f_1}{f_2} = \frac{10^{\left(A\left[Ch^+\right] + B\left[Ch^+\right]^2 - \frac{z^2 S\sqrt{I}}{1 + \left(\frac{3\sqrt{I}}{2}\right)}\right)}}{10^{\left(A^{'}\left[Ch^+\right] + B^{'}\left[Ch^+\right]^2 - \frac{z^2 S\sqrt{I}}{1 + \left(\frac{3\sqrt{I}}{2}\right)}\right)}}$$

If we transform back to the log form then we now get

$$\log\left(\frac{f_1}{f_2}\right) = \left(\frac{-z^2 S\sqrt{I}}{1 + \left(\frac{3\sqrt{I}}{2}\right)} + A\left[Ch^+\right] + B\left[Ch^+\right]^2\right) - \left(\frac{-z^2 S\sqrt{I}}{1 + \left(\frac{3\sqrt{I}}{2}\right)} + A'\left[Ch^+\right] + B'\left[Ch^+\right]^2\right)$$

As all the anions are monoanions, the Debye-Huckel terms cancel out thus giving us a more simple equation.

$$\log\left(\frac{f_1}{f_2}\right) = A\left[Ch^+\right] + B\left[Ch^+\right]^2 - \left(A^{'}\left[Ch^+\right] + B^{'}\left[Ch^+\right]^2\right)$$

We can change our equation to use delta A and delta B terms which represent the differences between the A / B and the A’ / B’ terms.

$$\log\left(\frac{f_1}{f_2}\right) = \Delta A\left[Ch^+\right] + \Delta B\left[Ch^+\right]^2$$

Now if we transform ourselves back to the non log form we get.

$$\frac{f_1}{f_2} = 10^{\left(\Delta A\left[Ch^+\right] + \Delta B\left[Ch^+\right]^2\right)}$$

We can then use this to create the equation which appeared in the paper

$$D_{Au} = \frac{K_{ex} U\, 10^{\left(\Delta A\left[Ch^+\right] + \Delta B\left[Ch^+\right]^2\right)}}{\left[Cl^-\right]_{aq}}$$

We can repeat this process for equations which a derived from activity function equations which include a θϕ term to take account of the effect of replacing aqueous media with the ethaline. Using the same method in algebra we then end up with.

$$D_{Au} = \frac{K_{ex} U\, 10^{\left(\theta\Delta\phi + \Delta A\left[Ch^+\right] + \Delta B\left[Ch^+\right]^2\right)}}{\left[Cl^-\right]_{aq}}$$

Assessment of skin exposure to the hydrocarbon diluents

The fraction of the oral reference dose (RfD) which would be adsorbed by a 70 kilo man who immerses his hands (840 cm^2 skin area) in the liquid every day. Using the following equation where P is the permeability constant, A the area, C the concentration in the fuel mixture and t (exposure time) the mass of the indivicual compounds in JP8 adsorbed into a person via the hands can be calculated.

$$Mass = PACt$$

Substance	RfD	Daily immersion limit
	mg day^{-1} kg^{-1}	(minutes)
Toluene	0.2	1
Ethyl benzene	0.2	3.7
Methylnapthelene	0.04	1.2
Mesitylene	0.04	1.8
JP8 fuel	-	22
Nonane	0.1	16.6
Decane	0.1	12.5
Undecane	0.1	27
Dodecane	0.1	47.6
Tridecane	0.1	44.1

Estimate of the energy consumption of a fume hood

A single fume hood which is 1 meter wide, is opened to a width of 0.1 m and has a face velocity of 0.5 ms^{-1}. Then in one hour this fume hood will remove 180 cubic meters of air. As air has a density of 1.2 kg m^{-3} and a heat capacity of *circa* 1 kJ kg^{-1} K^{-1} then on a Swedish winter's day (In Vara, Skara or Skövde) when the outside temperature is -20 ^{o}C and the workplace temperature is 20 ^{o}C. Then 2.4 kW will be required to heat the air delivered into the building to replace the air removed by the fume hood. While in London 540 W will be required when the outdoor temperature is the average 11 ^{o}C. If we were to assume the energy for one week of the additional heating demand created by the fume hood in the Swedish winter was in the form of diesel fuel (circa 10 kW hr L^{-1}), then this fuel would be sufficient to drive a modest car from Imperial College (London) to the outskirts of Aberdeen (Northern Scotland).

Second grinding campaign

A total of 13.637 kilos of printed circuit boards were ground and then sieved. The majority of these printed circuit boards were from computers and other similar electronic items.

Table of amounts of metal in solids which passed through sieves of a given size.

Sieve size (mm)	Mass (g)	Cu (g)	Fe (g)	Pb (g)	Ca (g)	Zn (g)	Ni (g)	Ba (g)	Mn (g)	Cr (g)	Au (g)	Mg (g)	Co (g)	Sr (g)
0,09	1366	34,09	26,59	14,56	19,84	10,13	7,92	21,13	6,25	4,15	0,723	6,59	0,20	1,86
0,18	2540	121,22	44,76	29,66	29,34	19,09	15,22	38,14	12,04	7,29	1,026	9,61	0,28	2,43
0,71	5067	775,91	89,73	59,14	40,01	34,11	50,59	61,35	20,62	11,79	2,171	16,24	0,96	3,34
1	6332	1204,86	115,43	75,06	42,51	55,66	73,35	70,30	24,48	13,60	3,543	17,27	1,37	3,44
1,4	7971	1609,81	162,93	103,58	49,13	68,35	102,07	75,86	28,58	15,48	4,618	24,24	2,23	3,91
2	9873	2066,08	209,96	113,04	57,49	100,16	124,05	76,98	30,01	17,71	5,361	24,96	2,51	3,91
4	13354	2732,72	288,89	119,47	82,14	131,47	142,14	78,02	30,97	23,38	5,869	27,09	2,84	3,91

Solvent extraction of barium, calcium, lithium, magnesium and strontium from perchlorate media.

Extraction of s block metals from sodium chloride

	Metal and wavelength (nm)					
	Lithium	Magnesium		Calcium		
[NaCl]	670.784	280.270	279.553	393.366	396.847	422.673
5.2	0.137	0.094	0.053	0.123	0.102	0.078
5.2	0.049	0.035	0.022	0.082	0.058	0.047
5.2	0.043	0.030	0.005	0.051	0.033	0.030

	Metal and wavelength (nm)					
	Strontium			Barium		
[NaCl]	407.771	421.552	346.446	455.403	493.409	233.527
5.2	0.018	0.014	0.053	0.111	0.070	0.093
5.2	0.012	0.015	0.032	0.046	0.036	0.047
5.2	-0.002	0.012	0.004	0.026	0.019	0.026

Extraction of s block metals from sodium nitrate solution

	Metal and wavelength (nm)					
	Lithium	Magnesium		Calcium		
[$NaNO_3$]	670.784	280.270	279.553	393.366	396.847	422.673
11.765	0.206	4.004	3.745	32.020	32.939	31.242
11.765	0.213	3.881	3.700	31.089	31.985	31.351
11.765	0.204	3.859	3.670	31.030	32.045	30.774

	Metal and wavelength (nm)					
	Strontium			Barium		
[$NaNO_3$]	407.771	421.552	346.446	455.403	493.409	233.527
11.765	0.569	0.572	0.658	0.068	0.049	0.041
11.765	0.582	0.573	0.634	0.090	0.027	0.010
11.765	0.576	0.636	0.616	0.018	0.014	0.013

Distribution ratios obtained with variable Cyanex 923 in solvent 70 in aqueous saturated NaClO$_4$ (8.14 M)

	Metal and wavelength (nm)					
	Lithium	Magnesium		Calcium		
Cyanex 923 (%)	670.784	280.270	279.553	393.366	396.847	422.673
0	0.059	0.050	-0.043	0.042	0.012	0.060
	0.001	-0.001	-0.049	0.031	0.007	0.026
	0.045	0.006	-0.034	0.022	0.008	0.052
10	1.858	189.838	177.711	∞	∞	∞
	1.986	215.762	203.193	∞	∞	∞
	1.959	218.187	206.578	∞	∞	∞
20	4.247	∞	∞	∞	∞	∞
	4.712	∞	∞	∞	∞	∞
	4.592	∞	∞	∞	∞	∞
30	7.179	∞	∞	∞	∞	∞
	6.690	∞	∞	∞	∞	∞
	6.812	∞	∞	∞	∞	∞
40	9.146	∞	∞	∞	∞	∞
	9.892	∞	∞	∞	∞	∞
	9.836	∞	∞	∞	∞	∞
50	11.858	∞	∞	∞	∞	∞
	12.322	∞	∞	∞	∞	∞
	12.528	∞	∞	∞	∞	∞
60	15.003	∞	∞	∞	∞	∞
	15.0547	∞	∞	∞	∞	∞
	14.226	∞	∞	∞	∞	∞
70	16.516	∞	∞	∞	∞	∞
	17.984	∞	∞	∞	∞	∞
	17.221	∞	∞	∞	∞	∞
80	18.902	∞	∞	∞	∞	∞
	19.620	∞	∞	∞	∞	∞
	19.953	∞	∞	∞	∞	∞
90	22.282	∞	∞	∞	∞	∞
	23.570	∞	∞	∞	∞	∞
	22.575	∞	∞	∞	∞	∞
100	26.698	∞	∞	∞	∞	∞
	28.005	∞	∞	∞	∞	∞
	28.647	∞	∞	∞	∞	∞

	Metal and wavelength (nm)					
	Strontium			Barium		
Cyanex 923 (%)	670.784	610.362	460.286	280.270	279.553	393.366
0	0.025992	0.023042	0.047562	0.020156	-0.00846	-0.02015
	0.013586	-0.00459	0.033561	0.009508	-0.01381	-0.03233
	0.023544	0.008866	0.034122	0.011424	0.000372	-0.01027
10	160.9413	167.5724	184.1291	14.69259	14.60358	15.16235
	180.4092	188.9323	205.1283	15.31072	15.25326	15.44886
	184.7626	192.8261	199.8612	15.34737	15.31437	15.83302
20	∞	∞	∞	29.83846	29.69823	31.18377
	∞	∞	∞	30.78599	30.6022	32.18974
	∞	∞	∞	30.58221	30.46331	32.13318
30	∞	∞	∞	41.40512	41.20348	44.01388
	∞	∞	∞	39.99551	39.99962	42.03472
	∞	∞	∞	41.87308	41.77815	44.55943
40	∞	∞	∞	50.41906	50.46749	54.21797
	∞	∞	∞	51.78712	51.65931	56.45096
	∞	∞	∞	52.92426	52.84756	57.64824
50	∞	∞	∞	57.46203	57.21499	62.48794
	∞	∞	∞	60.76024	60.59034	64.91307
	∞	∞	∞	60.00122	59.85009	65.08072
60	∞	∞	∞	66.33437	65.79589	71.93456
	∞	∞	∞	67.92329	67.57886	74.02516
	∞	∞	∞	65.45017	65.04734	71.89397
70	∞	∞	∞	71.59787	71.11667	77.00396
	∞	∞	∞	73.0955	72.68788	80.65665
	∞	∞	∞	73.18732	72.86038	82.11909
80	∞	∞	∞	74.21487	73.77353	81.69536
	∞	∞	∞	85.70462	84.91143	95.68675
	∞	∞	∞	72.31716	71.92396	80.16717
90	∞	∞	∞	87.8992	86.72684	99.10529
	∞	∞	∞	94.1111	92.92091	106.767
	∞	∞	∞	93.04857	92.05438	105.5938
100	∞	∞	∞	112.307	110.4195	127.9796
	∞	∞	∞	98.05077	96.80734	110.4606
	∞	∞	∞	111.6727	110.02	129.6328

Distribution ratios obtained with variable Cyanex 923 in solvent 70 in aqueous $NaClO_4$ (2.44 M)

	Metal and wavelength (nm)					
	Lithium	Magnesium		Calcium		
Cyanex 923 (%)	670.784	280.270	279.553	393.366	396.847	422.673
0	0.025469	-0.00146	-0.00715	-0.01055	-0.00802	0.014954
	-0.03193	0.007237	0.000632	-0.00608	-0.02031	-0.02951
	-0.01033	-0.0049	0.004068	-0.02346	-0.00223	0.016534
10	0.216468	10.30265	9.969615	127.2525	130.7437	136.3457
	0.212311	10.42856	10.08937	140.0544	144.0888	145.8607
	0.233435	10.14529	9.801699	139.8536	143.5684	148.1582
20	0.688249	32.16205	31.3121	∞	∞	∞
	0.634924	33.34883	32.52943	∞	∞	∞
	0.634734	32.4036	31.62271	126.7035	130.4054	129.0564
30	1.033231	53.0118	52.00878	120.1417	123.934	122.7564
	1.150979	55.83843	54.54191	∞	∞	∞
	1.133	58.04203	56.7433	∞	∞	∞
40	1.510438	79.45998	77.51674	∞	∞	∞
	1.546651	80.62965	78.81642	∞	∞	∞
	1.542081	76.24309	74.36332	∞	∞	∞
50	1.876383	102.1501	98.84379	∞	∞	∞
	1.820172	95.04387	92.29159	∞	∞	∞
	2.065325	111.4445	108.4176	∞	∞	∞
60	2.656329	144.9966	140.4053	∞	∞	∞
	2.398328	143.1027	138.9754	∞	∞	∞
	2.491388	135.1325	131.3892	∞	∞	∞
70	2.770875	155.3331	150.4279	∞	∞	∞
	2.770449	174.2563	167.793	∞	∞	∞
	3.097353	166.4322	161.4198	∞	∞	∞
80	3.12773	195.7666	190.4179	∞	∞	∞
	3.204722	192.3476	187.1778	∞	∞	∞
	3.362156	197.9788	192.884	∞	∞	∞
90	3.482829	∞	∞	∞	∞	∞
	3.607696	∞	∞	∞	∞	∞
	3.631861	∞	∞	∞	∞	∞
100	3.901605	∞	∞	∞	∞	∞
	3.91811	∞	∞	∞	∞	∞
	3.879219	∞	∞	∞	∞	∞

	Metal and wavelength (nm)					
	Strontium			Barium		
Cyanex 923 (%)	670.784	610.362	460.286	280.270	279.553	393.366
0	0.002442	0.004522	0.002575	0.003301	-0.01967	-0.01257
	0.003777	-0.00366	-0.00624	0.007911	0.00948	-0.00574
	-0.00537	0.008162	-0.01006	-0.01134	-0.01576	-0.02329
10	6.056398	6.377905	6.545627	2.718529	2.753754	2.827366
	6.194841	6.416437	6.577232	2.743627	2.856693	2.896409
	6.170484	6.257364	6.447219	2.852066	2.745098	2.785162
20	15.90939	16.63701	17.02534	6.760752	6.881896	7.040697
	16.4786	17.27262	17.67718	7.099687	7.189787	7.322036
	16.17676	16.93509	17.43785	6.860363	7.036647	7.280691
30	25.33395	26.45025	27.04648	9.885126	10.02615	10.62263
	25.54907	26.86566	27.66554	10.28727	10.37646	10.79015
	26.75959	27.92845	28.85049	10.42966	10.53481	10.94387
40	34.7503	36.37223	37.49326	13.17959	13.28394	14.08469
	35.32589	37.03776	37.68266	13.45457	13.55156	14.2513
	34.22233	36.06113	36.92955	13.20852	13.2766	13.96929
50	43.46288	45.53001	47.08813	15.82869	15.88469	16.95453
	42.74192	44.76057	46.14496	15.97858	16.05767	17.18566
	47.18315	49.60607	51.1104	17.15636	17.23912	18.53036
60	60.5672	63.93557	65.23079	21.32682	21.30781	22.9295
	58.9601	62.00573	64.41725	19.9552	19.9914	21.6025
	58.21491	61.50351	62.08198	19.93527	19.96705	20.77497
70	65.75948	69.31561	72.02065	22.23084	22.22106	24.0822
	70.02327	73.56796	75.8358	23.53138	23.5671	25.33185
	70.11231	73.94663	75.53938	23.87812	23.90615	25.74498
80	78.79979	83.30914	84.55799	25.66036	25.65319	27.52133
	79.18671	83.38902	86.91288	25.86102	25.87116	27.94968
	78.13824	82.52317	85.45721	25.47507	25.49497	27.55678
90	84.83363	89.33923	90.96234	27.40905	27.38695	29.74618
	92.4726	97.1042	101.1947	29.58168	29.52589	32.11606
	91.69692	96.89835	102.6526	29.91583	29.80792	32.29688
100	97.267	103.1202	106.0384	30.80801	30.69174	33.48736
	102.3677	107.9866	111.0745	32.35887	32.22853	35.51101
	104.1605	109.7081	112.9347	33.0572	32.89838	35.71466
	84.83363	89.33923	90.96234	27.40905	27.38695	29.74618
	92.4726	97.1042	101.1947	29.58168	29.52589	32.11606
	91.69692	96.89835	102.6526	29.91583	29.80792	32.29688

Distribution data for the s block elements being extracted from sodium perchlorate solution by 30 % Cyanex 923 in solvent 70.

		Metal distribution ratios			
Sodium perchlorate concentration	Perchlorate activity	Ba	Li	Sr	Mg
8,139824547	7,973159948	42,84954	7,203922	∞	∞
8,139824547	7,973159948	44,54523	7,492791	∞	∞
8,139824547	7,973159948	44,89507	7,490389	∞	∞
7,418695235	6,443056756	36,15118	5,66093	∞	∞
7,418695235	6,443056756	35,30335	5,772471	∞	∞
7,418695235	6,443056756	36,38066	5,848383	∞	∞
6,498558381	5,030423052	26,12438	4,259416	171,052	∞
6,498558381	5,030423052	26,94675	4,136085	202,0296	∞
6,498558381	5,030423052	27,1978	4,131544	183,8235	∞
5,63529639	4,0287894	19,93419	2,600755	100,1594	185,8789
5,63529639	4,0287894	19,41741	2,56178	100,26	195,1328
5,63529639	4,0287894	19,65568	2,565451	102,6486	202,3979
4,800248961	3,241178279	15,02523	1,946361	64,53834	128,4928
4,800248961	3,241178279	14,98063	1,899384	65,48184	132,9842
4,800248961	3,241178279	14,80967	1,896733	63,29165	123,2502
4,08215208	2,657810456	11,92351	1,461405	44,1767	83,19762
4,08215208	2,657810456	11,63877	1,248718	42,33004	86,4038
4,08215208	2,657810456	11,54817	1,115416	39,96769	75,90398
3,353408763	2,127101216	10,39538	1,200499	33,32763	65,75162
3,353408763	2,127101216	10,57097	1,186831	33,16498	64,35887
3,353408763	2,127101216	10,11639	1,138914	32,20268	63,86531
2,448525313	1,527104214	10,04124	1,087976	26,83621	55,01321
2,448525313	1,527104214	10,29699	1,214623	27,49029	56,84628
2,448525313	1,527104214	10,24953	1,127909	27,43933	56,52899
1,684998071	1,053663904	10,26921	0,982611	24,37651	51,23998
1,684998071	1,053663904	10,99414	1,049524	26,0629	54,99173
1,684998071	1,053663904	10,95772	1,009476	26,01623	54,31394
0,854682268	0,554062646	11,48867	1,098741	23,70891	53,08889
0,854682268	0,554062646	11,28711	1,065627	23,39457	52,84431
0,854682268	0,554062646	11,52972	1,086709	24,06883	49,65827

Lithium distribution ratios obtained with a 8.14 M sodium perchlorate solution using Cyanex 923 in either the skyNRG biokerosene or Euculyptol. The wavelength was 670.784 nm using an axial view of the plasma..

Cyanex 923 volume fraction (%)	D_{Li}	
	Euculyptol	skyNRG
0	0,151	-0,056
0	0,097	-0,010
0	0,104	-0,050
10	1,11	0,976
10	1,12	1,01
10	1,06	1,12
20	3,39	3,03
20	3,34	3,30
20	3,44	3,28
30	5,73	5,34
30	5,47	5,68
30	5,34	5,40
40	7,44	9,13
40	7,64	9,21
40	7,79	8,77
50	9,54	10,8
50	10,0	11,7
50	10,5	10,8
60	11,2	13,5
60	12,5	13,7
60	12.0	13,6
70	13,1	15,5
70	14,4	15,9
70	13,8	16,2
80	16,2	17,5
80	17,4	19,4
80	17,1	18,1
90	18,9	21,6
90	19,9	22,3
90	20,2	22,0
100	21,8	21,8
100	22,5	22,5
100	25,3	25,3

Barium distribution ratios obtained with a 8.14 M sodium perchlorate solution using Cyanex 923 in skyNRG biokerosene. Using an axial view of the plasma.

Cyanex 923 volume fraction (%)	D_{Ba}		
	455.403 nm	493.409 nm	233.527 nm
0	-0,019	-0,024	-0,023
0	-0,030	-0,017	-0,022
0	-0,018	0,014	-0,041
10	6,933	7,23	7,47
10	7,504	7,78	7,96
10	7,553	7,64	8,00
20	19,6	19,8	20,8
20	19,7	20,2	21,2
20	20,4	20,5	22,1
30	30,2	30,5	31,6
30	31.0	31,3	33,4
30	30,9	31,3	33,3
40	41.0	38,6	50,1
40	43,0	40,9	52,1
40	42,5	40,7	51,0
50	49,8	47,9	59,5
50	52,0	50,4	60,7
50	49,5	48,3	57,6
60	58,8	57,4	66,3
60	58,8	57,7	67,1
60	63,6	62,7	71,2
70	59,6	59,3	66,1
70	67.0	66,9	73,9
70	63,6	63,7	69,4
80	72,1	72,0	80.0
80	75,6	75,6	82,7
80	72,8	73.0	79,3
90	84,6	84,8	90,8
90	86,8	87,4	94.0
90	86,5	86,7	94,4
100	82,8	83,8	91,6
100	92,1	94.0	101
100	96,9	97,1	106

Barium distribution ratios obtained with a 8.14 M sodium perchlorate solution using Cyanex 923 in Euculyptol. Using an axial view of the plasma.

Cyanex 923 volume fraction (%)	D_{Ba}		
	455.403 nm	493.409 nm	233.527 nm
0	0,149	0,009	0,094
0	0,116	-0,018	0,077
0	0,101	0,007	0,079
10	4,83	4,43	4,88
10	4,98	4,63	5,06
10	4,85	4,64	4,96
20	16,1	15,6	16,9
20	16,7	16,5	17,4
20	16,5	16,4	17,4
30	25,8	25,8	27,3
30	24,7	25.0	26,6
30	25,1	25,5	27,0
40	31,0	31,8	33,5
40	32,8	33,6	35,6
40	32,9	34,1	35,2
50	39,0	40,6	42,2
50	40,4	42.0	42,4
50	40,3	42,4	43,8
60	42,3	44,9	46,1
60	48,1	51,3	51,0
60	46,8	49,4	51.0
70	51.0	53,9	55,5
70	51,7	55,1	56,5
70	53,4	56,4	58,4
80	60,2	63,1	65,1
80	66,6	69,1	72,5
80	65,2	67,2	70,5
90	70,6	72,9	75,0
90	76,0	77,7	82,7
90	79,7	81,4	86,0
100	82,8	83,8	91,6
100	92,1	94.0	101
100	96,9	97,1	106

Solvent extraction of the s-block metals using HVO100 as the diluent

Extraction data obtained with 5 % (v/v) cyanex 923 in HVO100

[NaClO4]	Ca 184,006 (Aqueous-Axial-iFR)	Mg 202,582 (Aqueous-Axial-iFR)	Sr 215,284 (Aqueous-Axial-iFR)
0,035351	0,34746	0,076269	0,078973
0,035351	0,335739	0,073081	0,071108
0,035351	0,362417	0,077491	0,077071
0,070702	0,659392	0,099861	0,090842
0,070702	0,618847	0,067662	0,073758
0,070702	0,641942	0,089575	0,082132
0,141404	1,19195	0,098109	0,104116
0,141404	1,186969	0,103756	0,107072
0,141404	1,12887	0,105349	0,112975
0,212106	1,426751	0,107448	0,114317
0,212106	1,404899	0,115314	0,117145
0,212106	1,454254	0,105223	0,121123
0,282809	1,535341	0,112305	0,089176
0,282809	1,704905	0,108121	0,102968
0,282809	1,690609	0,097893	0,09838
0,353511	1,845541	0,048583	0,106011
0,353511	1,951569	0,050554	0,106066
0,353511	1,918618	0,062288	0,104719
0,708916	2,712816	0,112839	0,086902
0,708916	3,073947	0,126709	0,091457
0,708916	3,281625	0,145477	0,106628
1,410713	4,924616	0,200962	0,170808
1,410713	5,059205	0,182857	0,154641
1,410713	4,656768	0,171123	0,14025
2,10907	7,473412	0,262559	0,235603
2,10907	7,378233	0,268405	0,239963
2,10907	7,46942	0,29111	0,257891
2,818856	10,72253	0,363846	0,319601
2,818856	10,33893	0,350655	0,31304
2,818856	9,619696	0,391913	0,337499
3,513638	8,473327	0,29229	0,264819
3,513638	9,4947	0,320037	0,26722
3,513638	9,72427	0,339114	0,277725
4,213989	11,29394	0,505818	0,434975
4,213989	12,49017	0,484592	0,420964
4,213989	13,40312	0,488214	0,401989
4,923612	18,51802	0,694737	0,621985
4,923612	19,72298	0,705263	0,648827
4,923612	18,09645	0,67148	0,603192

5,627009	24,20817	0,964432	0,841027
5,627009	20,97382	0,961462	0,85071
5,627009	24,04267	0,974597	0,865536

Barium, lithium, magnesium and strontium disitribution ratios obtained with 10 % (v/v) cyanex 923 in HVO100.

[NaClO4]	Li 670,776 nm	Mg 280,270 nm	Sr 215,284 nm	Ba 225,473 nm
6,326	0,324	18,415	15,955	1,483
6,326	0,375	22,067	18,783	1,769
6,326	0,336	20,686	18,318	1,735
5,981	0,372	19,943	15,841	1,653
5,981	0,365	22,352	16,334	1,614
5,981	0,363	16,131	14,515	1,585
5,627	0,215	12,796	11,146	1,416
5,627	0,216	17,708	12,692	1,466
5,627	0,231	16,637	12,406	1,469
5,279	0,319	13,247	10,084	1,388
5,279	0,199	15,430	10,822	1,349
5,279	0,165	13,126	9,890	1,305
4,924	0,094	9,386	6,623	0,981
4,924	0,130	10,826	7,930	1,194
4,924	0,115	10,403	7,805	1,196
4,571	0,206	9,345	6,516	1,131
4,571	0,151	8,981	6,242	1,066
4,571	0,145	9,454	6,575	1,171
4,214	0,113	6,506	4,533	0,866
4,214	0,127	6,708	4,609	0,872
4,214	0,062	6,931	4,683	0,883
3,880	0,115	5,776	3,920	0,831
3,880	0,140	5,657	3,799	0,765
3,880	0,103	5,858	3,957	0,828
3,514	0,089	3,994	2,759	0,653
3,514	0,081	4,480	3,099	0,739
3,514	0,098	4,637	3,152	0,750
3,180	0,055	4,533	3,141	0,900
3,180	0,096	4,788	3,289	0,911
3,180	0,111	4,485	3,092	0,867
2,819	0,048	3,576	2,478	0,787
2,819	0,096	3,459	2,400	0,776
2,819	0,070	3,490	2,411	0,775
2,109	-0,071	2,363	1,643	0,575
2,109	-0,002	2,267	1,634	0,593
2,109	-0,007	2,421	1,665	0,591

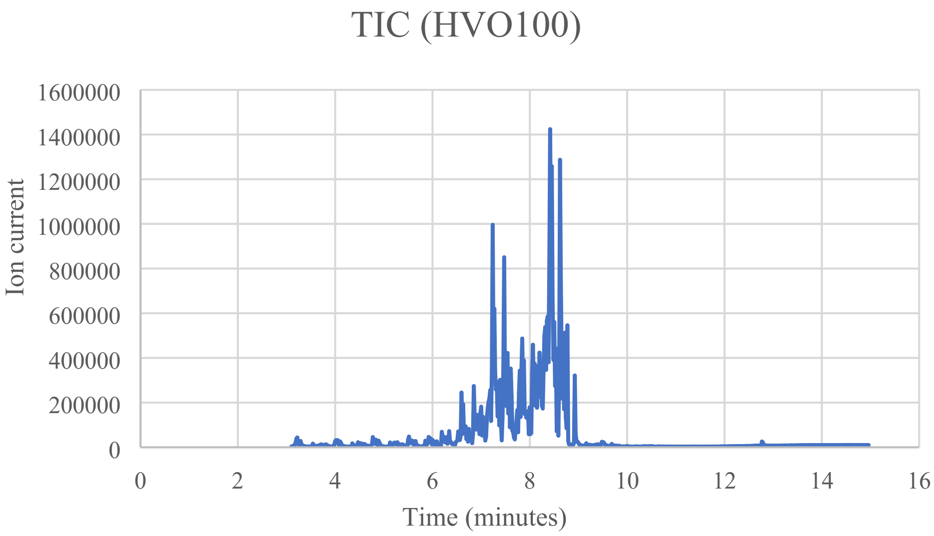
1,411	0,002	1,569	1,037	0,427
1,411	0,050	1,523	1,066	0,435
1,411	-0,026	1,595	1,083	0,455
0,709	0,151	1,059	0,725	0,357
0,709	0,143	1,046	0,724	0,370
0,709	0,067	1,012	0,693	0,343
0,354	0,145	0,557	0,363	0,200
0,354	0,024	0,584	0,388	0,208
0,354	0,025	0,533	0,393	0,190
0,184	-0,031	0,263	0,168	0,100
0,184	-0,007	0,278	0,176	0,108
0,184	-0,009	0,271	0,162	0,096

Distribution data for barium, lithium, magnesium and strontium obtained with 30 % cyanex 923 in HVO100

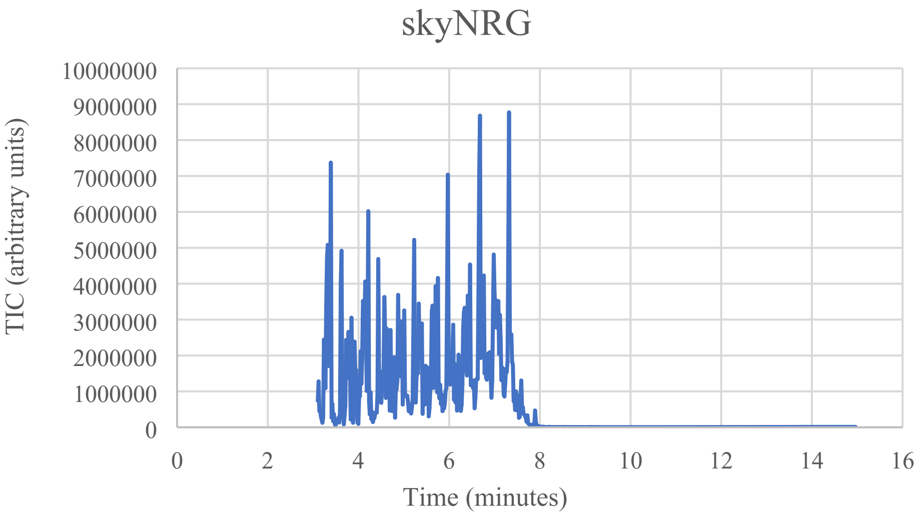
[NaClO4]	Li 610,362 nm	Mg 280,270 nm	Sr 215,284 nm	Ba 225,473 nm
6,681	5,819	∞	∞	25,584
6,681	6,023	∞	∞	25,187
6,681	6,115	∞	∞	25,090
6,326	4,711	∞	∞	20,875
6,326	4,691	∞	∞	21,131
6,326	4,717	∞	∞	22,316
5,981	3,926	∞	∞	20,698
5,981	4,047	∞	∞	18,429
5,981	3,784	∞	∞	18,532
5,627	3,290	∞	∞	16,071
5,627	3,274	∞	∞	16,692
5,627	3,367	∞	∞	18,000
5,279	3,027	∞	∞	15,188
5,279	2,925	∞	∞	15,068
5,279	2,980	∞	∞	15,728
4,924	2,283	∞	76,852	12,819
4,924	2,378	∞	82,625	13,875
4,924	2,431	∞	78,118	13,449
4,571	2,092	∞	62,676	12,114
4,571	2,105	∞	58,573	12,210
4,571	2,116	∞	65,786	12,128
4,214	1,802	87,350	50,178	10,512
4,214	1,784	80,671	48,166	10,732
4,214	1,737	91,809	51,765	10,394
3,880	1,653	66,899	39,829	9,744
3,880	1,612	79,879	43,501	9,476
3,880	1,627	76,988	42,716	9,705

3,514	1,403	60,507	33,930	8,454
3,514	1,382	58,111	33,572	8,530
3,514	1,428	65,119	35,719	8,728
3,180	1,318	52,417	29,274	8,068
3,180	1,329	53,314	29,629	8,162
3,180	1,222	55,260	30,187	8,204
2,819	1,140	47,806	26,035	7,628
2,819	1,081	43,973	24,919	7,627
2,819	1,123	46,648	25,594	7,530
2,461	0,991	38,888	21,946	6,873
2,461	0,989	37,866	21,696	7,219
2,461	0,994	40,098	22,489	7,317
2,109	0,939	34,625	19,098	6,738
2,109	0,985	35,817	19,439	6,961
2,109	0,955	34,294	18,971	6,945
1,757	0,926	31,254	17,183	6,781
1,757	0,841	30,658	17,186	6,879
1,757	0,912	33,423	18,261	7,108
1,411	0,856	29,416	15,913	6,347
1,411	0,876	28,435	15,717	6,517
1,411	0,886	29,591	16,010	6,504
1,050	0,872	27,498	14,930	6,485
1,050	0,832	23,622	13,091	5,885
1,050	0,852	24,627	13,418	5,779
0,709	0,793	19,361	10,068	4,799
0,709	0,823	19,554	10,213	4,894
0,709	0,871	21,593	11,067	5,129
0,354	0,687	11,756	5,795	3,074
0,354	0,665	11,611	5,747	2,940
0,354	0,637	11,666	5,761	2,951

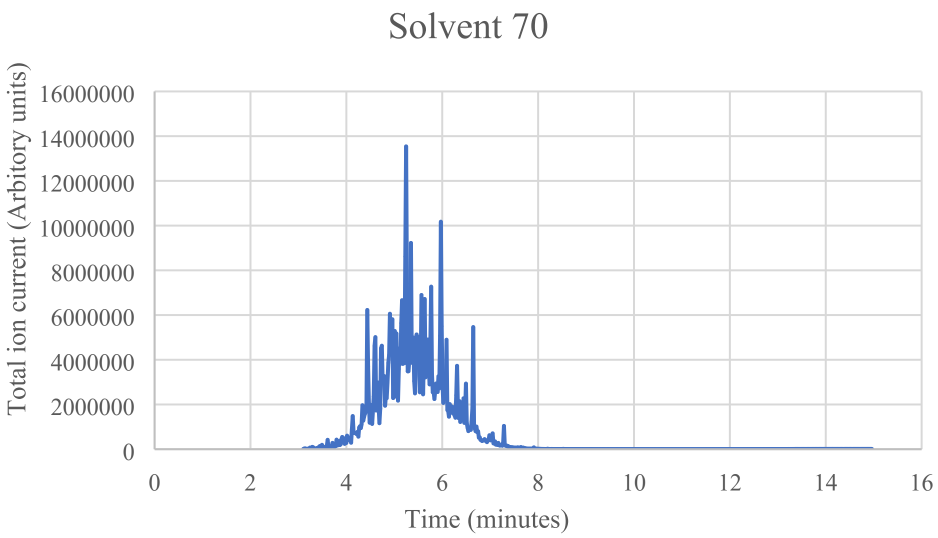
GCMS traces of kerosene grades



Total ion current for HVO100



Total ion current for skyNRG kerosene



Total ion current for the solvent 70 kerosene