Sub-Coulomb fission and transfer in collisions of ^{208}Pb with ^{238}U

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In earlier experiments to detect Coulomb fission in bombardments of ^{238}U with Xe ions[1] sub-Coulomb transfer cross sections were found to exceed the fission cross sections by more than one order of magnitude even at the lowest energies of 0.7 E_C where E_C corresponds to the Coulomb barrier. Thus we could not clearly distinguish between pure Coulomb fission and sequential fission after quasi-elastic transfer. Theoretical calculations by Oberacker[2] predict a Z_p^6 dependence of the Coulomb fission cross sections on the charge of the projectile. This should enhance the cross section by about a factor of 15 when using ^{208}Pb instead of Xe ions. Therefore we bombarded ^{238}U with ^{208}Pb ions at energies of 0.85 E_C and 0.80 E_C. After passing through the 1.7 mg/cm^2 thick targets these energies are reduced to 0.80 E_C, and 0.75 E_C.

After irradiation the targets were assayed for uranium (transfer products), barium, and zirconium (fission products)[1]. For E_{IN} = 0.80 E_C a fission cross section of 3.2×10^{-28} cm^2 was obtained if we assume the fission mass distribution was the same as for neutron-induced fission of ^{235}U. Transfer cross sections for ^{237}U and ^{239}U were measured as 3.1×10^{-28} cm^2 and 5.2×10^{-28} cm^2, respectively. These transfer processes can partially contribute to the observed fission cross section with the tail of the associated Q-value distribution that extends up to excitation energies above the fission barrier. If we make the pessimistic assumption that all transfers are associated with excitation energies above B_f resulting in a fission probability $P_f \approx 0.2$, then the measured cross sections for the residual nuclei ^{237}U and ^{239}U indicate that at most 50% of the observed fission yield of 3.2×10^{-28} cm^2 can be due to sequential transfer-induced fission. Oberacker[2] predicted a Coulomb-fission cross section of 2.7×10^{-28} cm^2 for ^{208}Pb on ^{238}U at 0.8 E_C (for the moment of inertia Θ being proportional to the deformation parameter a_0).

This is in fairly good agreement with our measured value which corresponds to an effective energy of $\sim$ 0.78 E_C, see Fig. 1. Recent experiments with ^{184}W ions[3] where the backscattered excited ^{184}W-projectiles could be measured in coincidence with the fission fragments, were also consistent with the Coulomb-fission cross sections predicted by Oberacker et al.[2].

Our experiments at E_{IN} = 0.85 E_C did not yield valuable results because the beam energy was not constant over the whole irradiation times. These experiments are no being repeated.

+Holder of an Alexander von Humboldt-Award, on leave from Brookhaven National Laboratory

[1] G. Franz et al., Z. Physik A291. 167 (1979)
[2] V. Oberacker et al., Phys. Rev. C20, 1453 (1979) and V. Oberacker, private communication
[3] H. Backe et al., Phys. Rev. Lett. 43, 1077 (1979)

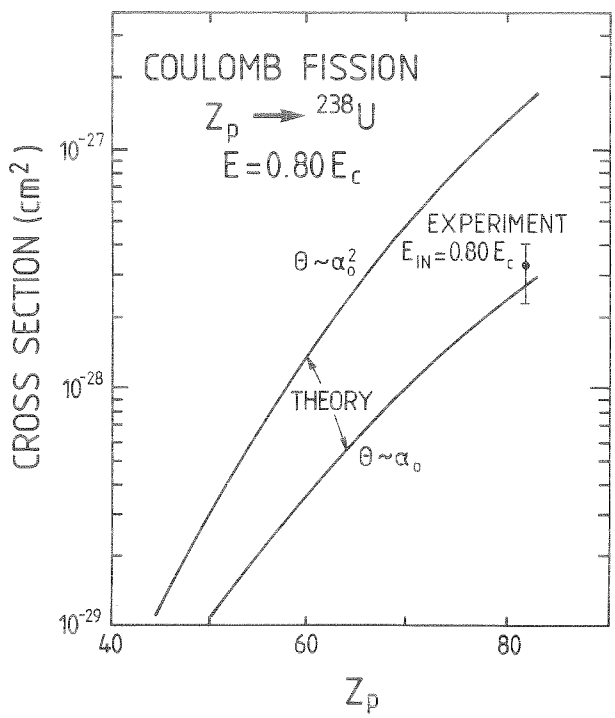

Fig. 1: Theoretical prediction of integral cross sections for Coulomb fission vs. projectile charge at 0.80 E_C by Oberacker et al.[2] The measured fission cross section in the $^{208}Pb+^{238}U$ system at an incident energy of 0.8 E_C is also indicated.

Energy dependence of the mass diffusion in $^{238}U+^{238}U$ collisions [B]

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Bombardments of thick ^{238}U targets with ^{238}U beams of 7.5 MeV/u incident energy have shown[1], that dissipative collisions between very heavy nuclei might be suitable for the production of superheavy elements. The diffusion model, generalized in order to take into account the superposition of different incident energies in the thick target, was used to extrapolate production rates into the region of superheavy fragments[2]. These calculations were based on a fit of an energy-independent, average diffusion coefficient ($D_Z=0.9\times10^{22}$ s^{-1}) to the reconstructed element yields[1] near Z=92. Folding of the predicted differential cross sections as a function of fragment charge and excitation energy ($d^2\sigma/dZdE$) with the relative width for neutron evaporation and spontaneous fission (Γ_n/Γ_f) as calculated by Moretto[3] yielded encouraging cross sections of the order of 10^{-34} cm^2 for Z=114. However, difficulties were encountered at the same time for Z=98,99 and 100, where folding of the predicted $d^2\sigma/dZdE$ with empirical Γ_n/Γ_f-values failed to reproduce the measured actinide cross sections. The discrepancies at Z=98-100 might be a shortcoming of the assumed[2] energy-independence of the diffusion coefficient. Therefore, we measured at several incident energies between 6.5 and 9.0 MeV/u cross sections for the production of transcurium elements[4] as well as for the production of their light complements. Fig. 1 shows as an example the energy dependence of the complementary Rn and Cf yields. It is evident that for the production of Cf only the lower incident energy bins contribute. Fig. 2 shows the measured element yields of residual products near Z=80 for three incident energies. The solid lines are predictions of the diffusion model where the theoretically predicted energy dependence of the diffusion coefficient, $D_Z \sim T$, was incorporated. While the model seems now to be capable of reproducing the data at the higher energies it clearly overestimates the cross sections for the near-barrier energies Since the production of surviving heavy products is mainly associated with the lowest bins of incident energy (see Fig. 1), the failure of the diffusion model to reproduce the cross sections in these bins casts some doubt on the relevance of previous predictions[2].

The problem is apparently connected with the fact that quasi-elastic few-nucleon transfer processes contribute a large fraction of the total reaction cross section, in particular at near-barrier energies. One is led to conclude that for dissipative collisions interaction radii considerably smaller than the quarterpoint radius (16.9 fm) are relevant. The data indicate that these interaction radii are somewhere between 15.4 and 16.0 fm.

[1] M. Schädel et al., Phys. Rev. Lett. 41, 469 (1978)
[2] C. Riedel et al., Z. Physik A290, 385 (1979)
[3] L. G. Moretto, Physics and Chemistry of Fission, I.A.E.A., Rochester, 1973
[4] M. Schädel, GSI-Report 79-8 (1979).

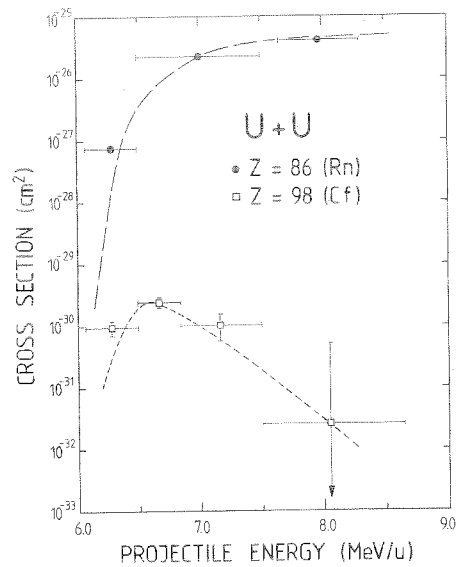

Fig. 1 Energy dependence of the complementary Rn and Cf yields.

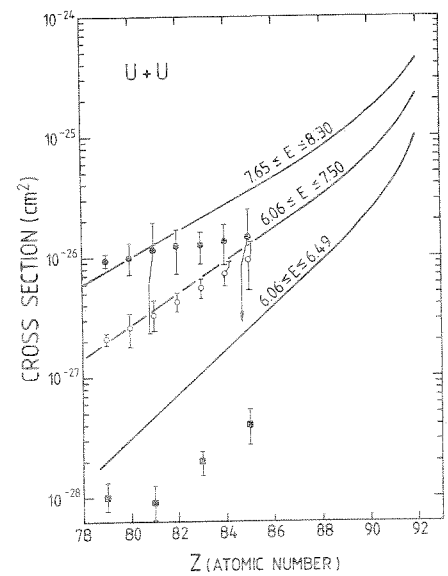

Fig. 2 Cross sections for ligh residual nuclei at different bins of projectile energies. The yields are increasingly depleted by sequential fission for the higher atomic numbers and for increasing incident energies. The curves are the results of the diffusion model.

Charge-, mass-, and energy distributions in the ^{132}Xe + ^{197}Au reaction

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We have previously reported[1] on the variances of the charge distributions $(\sigma_Z^{A'})^2$ at fixed primary mass numbers A' in the ^{132}Xe + ^{197}Au system at 900 MeV. These data are based on the reconstruction[1] of the primary cross section surface P(Z,A',E) from radiochemical stacked-foil experiments. This surface can also be used to calculate other moments of the charge- (Z), mass- (A') and energy (E) distributions. As an example we show in Fig. 1 the centroid of the element distribution $\langle Z_h \rangle$ for the gold-like fragments as a function of the total excitation energy of the dinuclear system. $\langle Z_h \rangle$ seems to be stable at the entrance channel charge up to excitation energies of ∿ 100 MeV. Then a drift toward more symmetric fragmentations is visible. It is noteworthy that the drift occurs only for energy losses near or exceeding those given by the Coulomb barrier of two spherical fragments touching at R = $1.16\ (A_1^{1/3}+A_2^{1/3}+2)$ fm. Thus the drift seems to appear with the onset of deformation in the exit channel. Similar observations were reported for the ^{86}Kr + ^{166}Er system[2].

Another interesting result is concerned with the ratio σ_A^2/σ_Z^2 of the variances of the integral mass- and charge-distributions at fixed values of dissipated energy. The large ratios of σ_A^2/σ_Z^2 for relatively small energy losses, see Fig. 2, indicate that peripheral collisions enhance neutron exchange relative to proton exchange. Such a behaviour may be indicative of the existence of a larger barrier for proton exchanges than for neutron exchanges at large internuclear distances.[3] These differences should disappear for a deeper interpenetration of projectile and target,[3] in qualitative agreement with the results shown in Fig. 2.

For excitation energies exceeding about 70 MeV the experimental ratios of σ_A^2/σ_Z^2 are in line with the relation $\sigma_A^2/\sigma_Z^2 = (1 + dN/dZ)^2$ which holds for fully correlated exchange of neutrons and protons. Here, dN/dZ is the average slope of the potential energy valley in the N-Z-plane as calculated by minimization of the potential energy for two touching liquid drops. If shell effects are assumed to be washed out at these excitation energies values of $\sigma_A^2/\sigma_Z^2 = 6$ are to be expected. The apparent hindrance of proton exchanges relative to neutron exchanges might be seen as an explanation for the slow rise[1] of the width of the charge distributions $(\sigma_Z^{A'})^2$ at fixed mass asymmetry with increasing energy loss. Then, one might expect that at a higher bombarding energy, the rise of $(\sigma_Z^{A'})^2$ should be much faster.

[1] J. Poitou et al., Phys. Lett. 88B, 69 (1979)
[2] G. Rudolf et al., Nucl. Phys. A330, 243 (1979)
[3] D.H. E. Gross, private communication (1980)

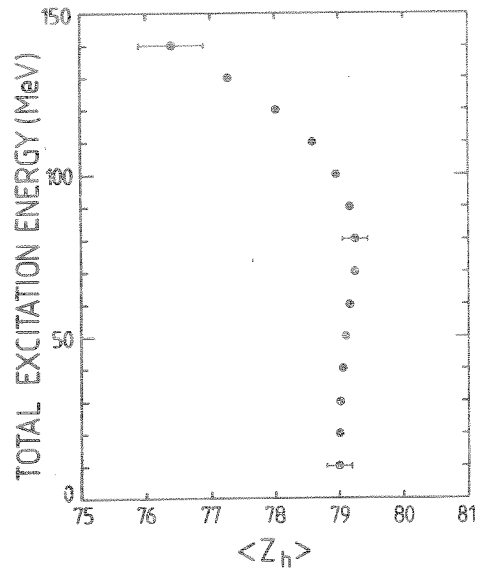

Fig. 1: Centroids of the heavy fragment charge distributions vs. total excitation energy in the dinuclear system.

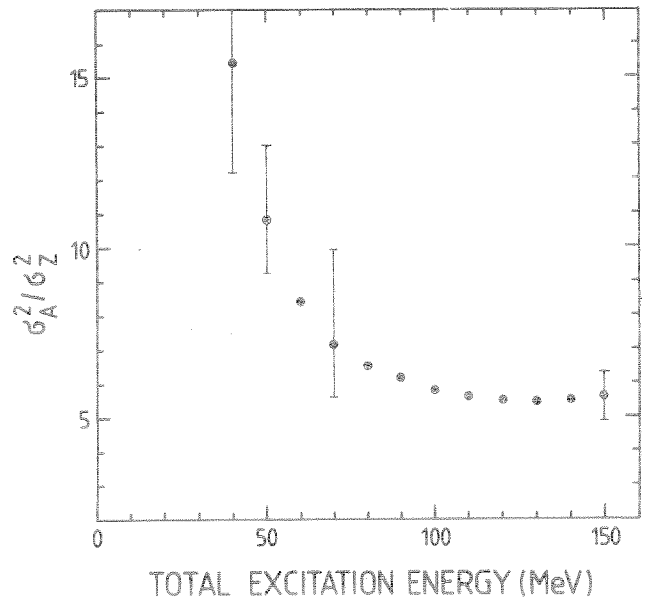

Fig. 2: Ratios of the variances of mass- and charge distributions σ_A^2/σ_Z^2 vs. total excitation energy of the dinuclear system.

Charge-, mass-, and energy distributions in the reaction of 7.5 MeV/u ^{238}U-ions with ^{197}Au B

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Radiochemical measurements of charge-, mass-, and energy distributions in damped collisions of ^{132}Xe-ions with ^{197}Au have provided evidence for very narrow variances of the charge distributions at fixed mass asymmetry[1]. These variances might be consistent with classical statistical fluctuations. Larger variances observed in the ^{86}Kr + ^{92,98}Mo system, on the other hand, were reported to present evidence for quantal fluctuations[2]. In order to find out whether light and heavy, symmetric and asymmetric systems behave in a different way, we have decided to investigate the ^{238}U + ^{197}Au system as an example for a very heavy asymmetric system.

Self-supporting targets of 520 µg/cm^2 ^{197}Au were bombarded with 7.5 MeV/u ^{238}U-ions and the target-like reaction products were stopped in stacks of thin mylar foils (6 µm) at several laboratory angles covering the range $22^o \leq \Theta_{lab} \leq 62.8^o$. After bombardment each foil, corresponding to a given range of angles and velocities of the Au-like products, was dissolved and chemically separated into fractions of the elements Hf, Ta, Ir, Pt, Au, Hg and Tl. Differential cross sections

$$\int_{R_1}^{R_2} \int_{\Theta_1}^{\Theta_2} (\delta^4\sigma/\delta Z \delta A \delta R \delta\Theta)\ \delta R \delta\Theta$$

for individual isotopes were then determined by γ-ray counting (R = range in mylar, Θ = laboratory angle).

Typical data for ^{196}Au in its 12$^-$ isomeric state are shown in Fig. 1. At each angle, the range distribution is indicated by the number of the mylar foil in the stack in which the Au fragment has been stopped. The maximum of the angular distribution is found near the grazing angle (48^o). Fig. 2 shows the isotope distributions for Au isotopes at four adjacent angular ranges. Similar to the ^{132}Xe + ^{197}Au system[1], the yield curves can be decomposed into a quasi-elastic and an inelastic component. While the quasi-elastic transfer dominates near the grazing angle, this component is essentially absent at smaller angles. The variances of the distributions for the damped compoment increase from $\sigma_A^2 = 2.2$ to $\sigma_A^2 = 5.5$ from the grazing angle to the smaller angles. Simultaneously their centroids are shifting continuously toward lower mass numbers.

Evaluation of similar data for Hf, Ta, Pt, Hg and Tl is in progress. Centre of mass transformation and the further data reduction in terms of the reconstruction of the primary cross section surface P(Z,A',E) will proceed in the same way as performed previously[1]. The magnitude of the charge variances σ_Z^2 at fixed mass asymmetry resulting from this analysis should allow to discern classical statistical fluctuations from quantal zero point oscillations[2].

[1] J. Poitou et al., Phys. Lett. 88B, 69 (1979)
[2] M. Berlanger et al., Z. Phys. A291, 133 (1979)

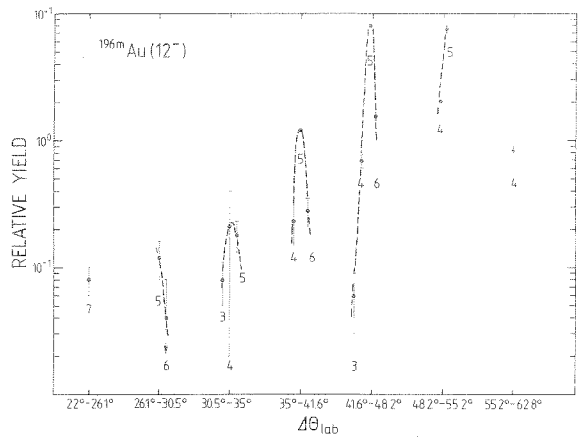

Fig. 1: Relative yields for ^{196m}Au at different laboratory angles. The numbers 3-7 denote the number of the mylar foil in the stack in which the Au fragment has been stopped.

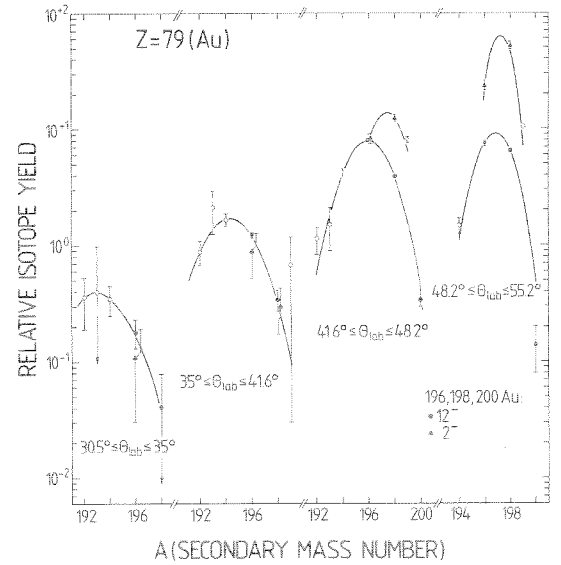

Fig. 2: Isotope distributions of Au isotopes at different laboratory angles. For ^{196,198,200}Au full circles denote the 12$^-$ isomeric states, while full triangles denote the 2$^-$ ground states.

Search for superheavy elements in the $^{238}U+^{238}U$ reaction using gas-phase and solution chemistry [B]

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Already the first experimental studies of damped collisions between two ^{238}U nuclei have indicated that this system may offer a novel approach to the synthesis of superheavy elements[1,2]. We have therefore performed during the past two years several attempts to identify superheavy elements in thick uranium-metal targets bombarded with 8.6 MeV/u ^{238}U beams. After bombardment the targets were processed with two chemical separation procedures based on entirely different principles with regard to the chemical behaviour of superheavy elements. One of these procedures, the gas-phase chemistry, is based on the predicted volatility of superheavy elements in their elementary state; it should cover elements 112 through 117. The other procedure, the solution chemistry which should cover elements 108 through 116, is based on the expected formation of strong anionic complexes with bromide ions and on the expected strong affinity to sulfur as is utilized in the solvent extraction with diethyldithiophosphate.

In 1979 we have continued this series of experiments[3] with two bombardments in which only the solution chemistry was applied. In addition, provisions were made to condense noble gases (element 118) and other species that are volatile at room temperature, as is described in a following contribution[4].

The two bombardments are listed under Nos. 5 and 6 in the Table which gives also the data for the preceding experiments[3] and the noble gas fraction[4]. 31 days after bombardment No. 6 a single fission fragment (23 MeV + energy loss in the 30 µg carbon foil) in coincidence with one neutron was observed. For this fraction a minor uranium contamination cannot absolutely be excluded.

Table: Summary of relevant quantities for searches for superheavy elements in bombardments of thick ^{238}U targets with 8.6 MeV/u ^{238}U ions. S=solution chemistry, G=gas phase chemistry, Gases=condensation of gaseous species.

Bombardment	Chemistry	Beam integral	Counting time [d]	Observed Sf-events
1	S	5×10^{15}	51	0[a]
2	G	7×10^{15}	275	2[a]
3	G+S	3.6×10^{16}	117	1[b]
4	G+S	4×10^{16}	220	0[b]
5	S	2.9×10^{16}	100	0[a]
6	S	2.8×10^{16}	160	1[b]
5+6	Gases	5.7×10^{16}	99	2[c]

a) Counting samples placed between two opposed surface barrier detectors. Registered events are SF-coincidences, efficiency for detecting two fission fragments in coincidence 60%.

b) Surface barrier detector-pair placed inside a neutron-multiplicity counter. Registered events are one or two detected fission fragments in coincidence with neutrons. Efficiency for the detection of one neutron 30%.

c) Gaseous species condensed on a copper cryostat faced by one single surface barrier detector.

In order to estimate upper cross section limits for the production of spontaneously fissioning superheavy elements, we start with two observed events per 4×10^{16} particles which are still compatible with 6 events at 95 % confidence level. We assume 75 % chemical yield and a constant excitation function between 8.6 MeV/u and the interaction barrier. The results, denoted by "chemistry", are shown in the Figure as a function of the half-life of the superheavy nuclei. Also given are upper cross section limits reported by Hildenbrand et al.,[1] ("implanted recoils"), Junglcas et al.[6] ("gas-jet") and Gäggeler et al.[5] ("wheel").

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[1] K.D. Hildenbrand et al., Phys. Rev. Lett. 39, 1065 (1977)
[2] M. Schädel et al., Phys. Rev. Lett. 41, 469 (1978)
[3] N. Trautmann et al., GSI Annual Report 1978, p. 70
[4] H. Gäggeler et al., this Annual Report p. 61
[5] H. Gäggeler et al., this Annual Report p. 62
[6] H. Jungclas et al., Phys. Lett. 79B, 58 (1978).

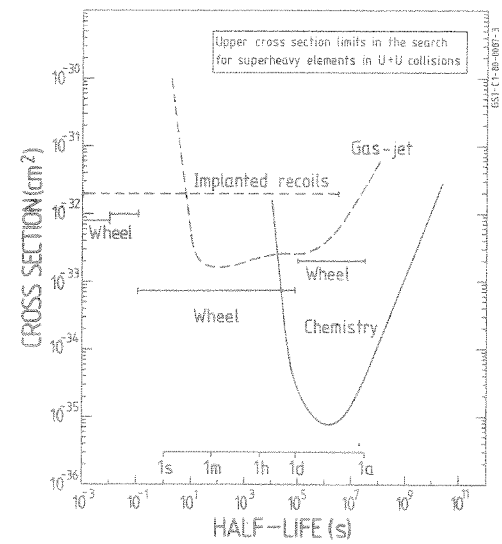

Figure
Upper cross section limits in the search for spontaneously fissioning superheavy elements in the $^{238}U+^{238}U$ reaction.

Search for Gaseous Superheavy Elements in ^{238}U on ^{238}U Collisions

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Several authors, e.g. Pitzer[1], draw attention to the fact that due to closed electron shells and subshells, superheavy elements with Z ≈ 112, 114, 118 might be very inert and similar to noble gases. In the chemical procedures used in the experiments summarized in the preceding report[2], gaseous reaction products like radon were lost. The only experiment aimed at the search for gaseous superheavy elements in the U + U reaction was done by Aumann et al[3] using a gas jet system. It yielded an upper cross section limit of 1.5×10^{-33} cm^2 whereas values as low as 10^{-35} cm^2 are accessible with the uranium beam intensities now available at the UNILAC. Therefore, we extended our chemical experiments to search also for spontaneously fissioning gaseous reaction products. As an internal tracer the noble gas radon was assumed to show a representative behaviour for gaseous superheavy elements.

For these experiments, the targets from bombardments 5 and 6 listed in the Table in Ref.2 were dissolved in a closed apparatus and gaseous products were swept out of the reaction chamber using He as carrier gas. The gas was dried by H_2SO_4 and KOH and passed through a U-tube filled with quartz powder which was held at liquid N_2 temperature. This trap was connected to a counting chamber, evacuated to 10^{-2} Torr and then warmed up to room temperature.

Gaseous products were diffusing into the chamber and were adsorbed on the surface of a Cu rod immersed in liquid N_2. The deposition zone was faced by a surface barrier detector to count α-particles and fission fragments in 2π geometry. The condensation efficiency was measured using a ^{226}Ra (^{222}Rn) emanation source and was found to be ≥ 90 %.

Counting of gaseous reaction products was started 1.9 h after the end of the irradiations. Two spontaneous fission events (80 MeV and 103 MeV) have been observed during a counting time of 99 days. We do not attribute any significance to these single events since such a count-rate corresponds to the usual electronic background of our detectors. These two observed events correspond at a 95 % confidence level to the following production cross section limits: 2×10^{-35} cm^2 for half-lives from 2 to 100 d, and 1.6×10^{-34} cm^2 for 100 d.

The measured α-spectra can be explained by Rn isotopes and their daughter products. Deduced production cross sections for Rn isotopes are shown in the Figure. Due to their short half-lives the isotopes A = 212 - 220 were not accessible in these experiments. The cross sections are not corrected for growth from precursors and have therefore to be considered as cumulative values. For the neutron-rich isotope 1.9 h ^{224}Rn a remarkably high cross section of 20 μb was measured which demonstrates the possibility for producing new neutron-rich isotopes of Po and At in U + U collisions.

[1] K. S. Pitzer, J. Chem. Phys. 63, 1032 (1975).
[2] N. Trautmann et al., this Annual Report, preceding contribution
[3] D.C. Aumann et al., Phys. Lett., 82 B, 361 (1979)

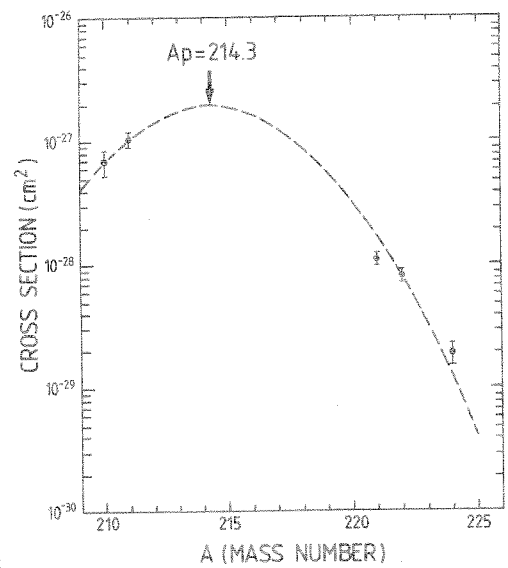

Figure Cumulative formation cross sections for radon isotopes in ^{238}U + ^{238}U collisions at ≤ 8.6 MeV/u bombarding energy.

Search for superheavy elements with half-lives down to 1 msec in ^{238}U on ^{238}U collisions

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In order to improve the sensitivity in the search for short-lived spontaneously fissioning superheavy elements in uranium on uranium collisions, a rotating wheel system was developed. In this system products recoiling from a rotating uranium target are stopped in a stack of aluminium catcher foils covering an emission angle of $\pm 55^{0}$ (lab)[1]. The stopped activities are continuously rotated out of the beam into shielded positions with static Macrofol fission track detectors positioned on either side of each rotating foil. After their on-line exposure, the fission track detectors are etched with KOH and the tracks are made visible by the spark technique. In order to search for long-lived superheavy elements which might have escaped radiochemical detection due to unexpected chemical behaviour, off line exposures of additional track detectors were performed. These detectors were exposed to the catcher foils after the end of bombardment for varying lengths of time. In a series of experiments, 11 mg/cm^2 thick metallic U-targets were bombarded with 7.6 to 8.3 MeV/u U-beams, while the catcher foils rotated at various velocities suitable for the detection of activities with half-lives of $\geq$ 1 msec. Due to the kinematics of damped reaction processes in the U+U interaction, the collected products are produced in the energy range from 7.4 MeV/u down to the interaction barrier. We observed four different spontaneous fission activities with half-lives of 1.1±0.1 msec and 13±5 msec, a product decaying largely during the irradiation time (100 msec $\leq$ T 1/2 $\leq$ 1 d) and a long-lived component with T 1/2 >> 1 d. Probable assignments of these activities, together with their production cross sections are summarized in the Table. Also listed are values from the literature. Due to the counting statistics and assumptions about the detection efficiency for fission fragments the reported cross sections are accurate within a factor of two. We attribute the long-lived spontaneously fissioning activities to ^{256}Fm and ^{254}Cf. Our cross sections are in good agreement with radiochemical data[2]. The msec-activities can most probably be assigned to the fission isomers $^{244mf}Am$ and $^{242mf}Am$. From the radiochemically determined Am yields listed in the Table, isomer to ground state ratios of 2.7×10^{-5} and 2×10^{-5} for ^{244}Am and ^{242}Am are deduced, respectively. These are lower than what is observed in light particle induced reactions, where ratios of the order of 10^{-4} are reported[3]. Note that the radiochemically determined Am yields have to be divided by a factor of two since target- and projectile-like fragments were not separated, whereas only target-like reaction products are detected with the rotating wheel system. From the observed range and angular distributions of the detected actinides within the foil stack their excitation functions can be deduced. They all show a similar shape with a maximum cross section at $E_U \sim 6.6$ MeV/u and a FWHM of 150±50 MeV (lab) in agreement with reported excitation functions for heavy actinides[2].

In conclusion, the sensitivity of the search for superheavy elements with this technique is limited by the production of spontaneously fissioning actinides. No evidence for the production of spontaneously fissioning acitivities with cross sections exceeding those for $^{242/244mf}Am$, ^{256}Fm and ^{254}Cf is found. Our upper cross section limits are included in the Figure of Ref. 4.

[1] W. Weber et al., GSI Annual Report 1978, p. 184

[2] M. Schädel et al., Phys. Rev. Lett. 41, 469 (1978) and GSI-Report 79-8 (1979)

[3] V.L. Kuznetsov et al., Nucl. Phys. A324, 29 (1979)

[4] N. Trautmann et al., this Annual Report, p. 60

Table

Nuclide	$T_{1/2}$	cross section	(Lit. (Ref. 2))
$^{244mf}Am$	1.1 msec	8×10^{-33} cm^2	6×10^{-28} cm^2 (^{244g}Am)
$^{242mf}Am$	14 msec	1×10^{-32} cm^2	1×10^{-27} cm^2 (^{242g}Am)
^{256}Fm	2.6 h	7.5×10^{-34} cm^2	6×10^{-34} cm^2
^{254}Cf	60.5 d	3.5×10^{-33} cm^2	2×10^{-33} cm^2

Search for superheavy elements and heavy actinides in the $^{238}U + ^{248}Cm$ reaction [B]

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Attempts of the GSI-Mainz collaboration to detect superheavy elements in damped collisions of two ^{238}U nuclei have failed[1], setting cross section limits of 10^{-32} cm^2 to 10^{-35} cm^2 for half-lives between 1 ms and 1 a. As we have demonstrated[1] it is most probably not reasonable to increase the bombarding energy in order to increase the production rates for superheavy elements because only the low-energy tails of the primary charge distributions contribute. Their enhancement is the essential problem. Riedel and Nörenberg[2], on the basis of an analysis of the $^{238}U + ^{238}U$ data[3] at $\leq$ 7.5 MeV/u, predicted for Z=114 an increase in the partial cross sections contained in the low energy tails ($E \leq 30$ MeV) by two orders of magnitude if a thick ^{248}Cm target is used instead of ^{238}U.

In October 1979 the first bombardments of 7 mg/cm^2 ^{248}Cm-metal targets with ^{238}U beams were performed. These targets contain a spontaneous fission activity of 2×10^9 events/day. The targets were previously tested with an electron beam gun and it was found that their thermal stability was excellent up to target temperatures $\geq 900^oC$. The target apparatus is schematically shown in Fig. 1. It served for two different experiments. Accelerator and beam line were protected against accidents with the highly active target by a Mo-window. Window and target were cooled by a fast nitrogen gas flow and the target itself by an additional He gas jet. Impurities in the gases were removed by a gas purification system. The target temperature was monitored online by an infrared thermometer. The outgoing He gas was assayed for nitrogen (M=28) by a quadrupole mass spectrometer (QMS). A sudden increase of the QMS signal for M=28 indicated that the target had developed a hole so that nitrogen entered the recoil chamber. Macropulses of the beam were spread over the target area by a beam wobbler. In case of a break of the target and the window a fast acting valve would be closed. To provide maximum protection, the wobbler, cooling gas flow, target temperature, accelerator vacuum, peak beam current etc. were interlocked to shut the beam off instantly if preset parameters were exceeded. The whole target apparatus was operated inside a glove box and all chemical separations were also carried out in glove boxes.

Counting of the isolated actinide and superheavy element fractions is still being continued. Qualitatively, we can state that the decrease in cross sections for the transuranium isotopes is as steep as the decrease for the transuranium nuclei in the $^{238}U + ^{238}U$ reaction. ^{259}No was possibly observed with an upper limit of 20 nb. ^{102}No Preliminary upper limits for the production of superheavy elements are of the order of 10^{-33} cm^2. The lower sensitivity of these experiments as compared to the $^{238}U + ^{238}U$ experiments is due to the lower total beam intensity at which the bombardments had to be terminated because the targets developed stress cracks. It is not yet clear whether this cracking was caused by metallurgical, chemical, thermal, or radiation damage effects and whether the problem can be solved. This, however, is necessary in order to increase the sensitivity to $\leq 10^{-35}$ cm^2 in future experiments.

+Also at GSI Darmstadt

[1] J.V. Kratz, Paper presented at the Int. Conf. on Extreme States in Nuclear Systems, Dresden, Febr. 1980, GSI-Report 80-1; see also preceding contributions to this Annual Report.

[2] C. Riedel et al., Z. Physik A290, 385 (1979)

[3] M. Schädel et al., Phys. Rev. Lett. 41, 469 (1978

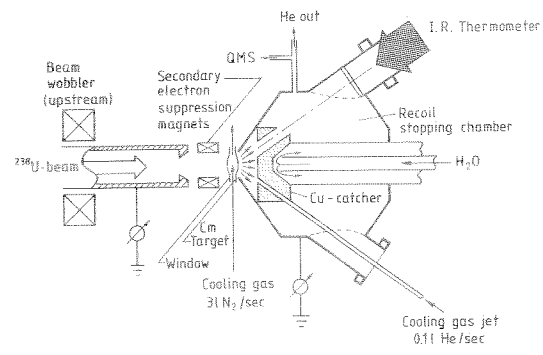

Fig. 1: Target apparatus for the $^{238}U + ^{248}Cm$ experiments

Stopping power measurements with 10 MeV/u ^{238}U ions

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For the design of the $^{238}U+^{248}Cm$ experiment[1] and of $^{238}U+^{238}U$ experiments using a wheel system[2] it was necessary to measure the energy loss of ^{238}U projectiles in thick ^{238}U targets and in Al, Mo, Ta, and W metal foils. The foils were prepared by rolling. In the case of ^{238}U oxidation of the surface layer was prevented by evaporation of thin Ni layers onto the uranium foil which had previously been cleaned by sputtering. After rolling the thickness of the Ni layer was reduced to 34-63 µg/cm^2. The targets were transported and inserted into the beam line under Ar atmosphere. The thicknesses of the foils were determined by weighing. Several energies of the primary ^{238}U beam between 5.9 and 10.0 MeV/u as determined by the UNILAC time-of-flight system were used to calibrate a surface barrier detector which was inserted directly into the reduced beam. The same detector was then used to determine the degradation of the incident beam energy in a given metal foil.

Projectile energies after transversing different foil thicknesses were calculated by the use of the Northcliffe and Schilling tables.[3] The figure shows for uranium foils the deviations between calculated (E_{NS}) and measured values (E_{OUT}) for three different incident energies (E_{IN}) of 10.0, 8.6, and 5.9 MeV/u. For the energy range of interest in the $^{238}U+^{238}U/^{248}Cm$ experiments,[1,2] i.e. 6 to 10 MeV/u, the differences between measured and tabulated values are below 3 %. The table shows that, except for Al, there is no dramatic deviation from the Northcliffe and Schilling tables. In this table the stopping power values are compared after averaging different foil thicknesses. For ^{238}U-energies around 5 MeV/u our data for Al and U are in agreement with those of Bimbot et al.,[4] who report a deviation $\varepsilon = +17\pm3\%$ for Al and $\varepsilon = -11\pm5\%$ for U.

Table: Deviations of experimental average stopping powers S_{exp} from Northcliffe-Schilling stopping powers S_{NS} for ^{238}U ions:

$$\varepsilon = \frac{S_{exp} - S_{NS}}{S_{NS}} \times 100 \quad [\%]$$

E_{IN}	5.9 [MeV/u]	8.5 [MeV/u]	10.0 [MeV/u]
Al	+18.1±2.5		+22.0±5.0
Mo	+ 6.6±2.5		+ 3.7±2.5
Ta	+ 0.5±2.0	- 5.0±5.0	- 0.8±2.5
W	+ 4.2±4.0		- 1.5±2.5
U	-12.0±5.0	- 4.0±2.5	- 2.4±3.2

[1] M. Schädel et al., this report p.
[2] H. Gäggeler et al., this report p.
[3] L.C. Northcliffe, R.F. Schilling, Nucl. Data Tables A7 233 (1970)
[4] R. Bimbot et al., Report IPNO-RC-80-0a, (1980)

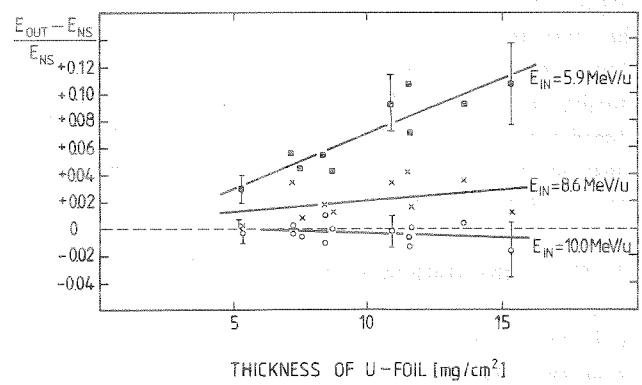

Fig. 1: Relative deviation of the energy E_{OUT} of ^{238}U-ions (after passing various ^{238}U-metal foils) from the predicted[3] energy E_{NS}.

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Continuous separations of reaction products in a thermochromatographic column with various halogenating agents as reactive gases

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The combination of a gas-jet recoil-transport system with a thermochromatographic column[1] has been applied for continuous chemical separations of fission products in form of volatile chlorides, bromides and iodides. A nitrogen gas-jet containing potassium chloride clusters was used to transport the fission products produced in the Mainz reactor from the target area to the thermochromatographic column. The clusters were stopped in a quartz-wool plug located in a quartz column with an inner diameter of 4 mm which was filled with quartz powder. The plug was heated to 960°C in order to destroy the clusters and to enable a complete halogenation. The first 8 cm of the column were kept at a constant temperature of 960°C; along the other part of the column a negative temperature gradient of ≈18°/cm was established. For halogenation of the fission products a mixture of the reactive gas with nitrogen was fed into the column through a by-pass. The element distribution along the thermochromatographic column was measured after removal of the column from the oven by γ-ray spectroscopy using a lead collimator.

In an earlier report[2] the element distribution of the volatile chlorides was given. With HBr and HI (8 vol% in the gas stream) quite similar thermochromatograms were obtained. As an example the Figure shows the element distribution with HI in the carrier gas at a flow rate of 1.3 l/min and after an exposure time of 15 min.

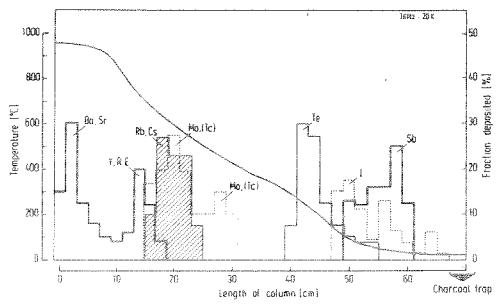

Fig. 1: Element distribution in the thermochromatographic column with 8 vol-% of hydrogen iodide in the N_2 carrier gas

With both agents the alkaline earth elements were found in the isothermic part of the column adjacent to the quartz-wool plug. The lanthanides are deposited at lower temperature with HI than with HBr. Rb and Cs appear at around 660°C and Mo forms a rather broad peak centered at 570°C. With HBr molybdenum is deposited at a lower temperature. Technetium is found in the same zone as molybdenum and therefore no clear statement on its behaviour can be made since the technetium nuclides measured after exposure are formed exclusively in the β^--decay of Mo. Proceeding to lower temperature regions tellurium is found at 210°C and antimony in a region between 100°C and room temperature. Iodine activity is deposited together with iodine from decomposition of HI in a visible adsorption zone between 150°C and room temperature.

The deposition temperatures of the elements in the thermochromatographic column and in the following charcoal trap as obtained with HCl, HBr and HI are summarized in the Table. In general one can say that the deposition temperatures for the chlorides and iodides are lower than for the bromides.

Table: Deposition temperatures of fission product halides in a thermochromatographic column

Element	Deposition temperatures in °C with		
	HCl	HBr	HI
Rb	650	730	660
Cs	630	730	660
Sr,Ba	960	960	960
Y,R.E.	780	850	760
Mo	20	140	590;410
Tc	50;ch.	160	590;430
Sb	30;ch.	100	35
Te	180	290	210
Br,I	ch.	ch.	150 - ch.

ch. = charcoal trap

Elementary bromine and iodine are only applicable up to a concentration of 12 vol%; at higher concentrations the column is plugged by these agents within a very short time. With Br_2 and I_2 as reactive gases the alkaline earth elements and the lanthanides are not volatilized. The other elements are found at higher temperatures than with hydrogen halides.

On the other hand, with a mixture of BBr_3+Br_2+N_2 the alkaline earth and lanthanide elements could be volatilized almost completely and were found in a broad zone between 500 and 600°C. The other fission products were deposited in the cold part of the column and the charcoal trap without further separations.

[1] U. Hickmann et al., Nucl. Instr. Meth., in press
[2] N. Greulich et al., GSI-Bericht 79-11, 154 (1979)