Supporting Information

Transition-metal-free Nucleophilic ^{211}At-astatination of Spirocyclic Aryliodonium Ylides

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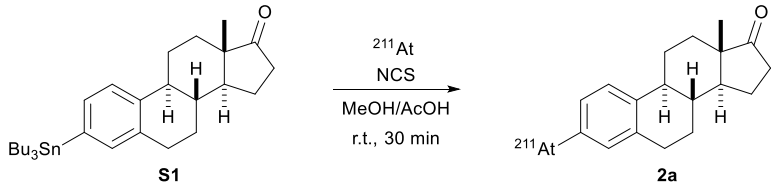
1. General information

Materials: Commercially available *N*,*N*-dimethylformamide (KANTO CHEMICAL CO., INC, Super Dehydrated grade) were used without further manipulation unless otherwise stated. Aryliodonium ylides **1** were synthesized according to the literature.[1,2] Astatine-211 was produced from an elemental Bi target via the $^{209}Bi(\alpha,2n)^{211}At$ nuclear reaction with a 34 MeV alpha beam for 3–4 h at a beam current of 12–13 μA using the NIRS-QST isochronous cyclotron AVF-930 in National Institutes for Quantum & Radiological Science & Technology (QST), Chiba, Japan. ^{211}At was recovered from the irradiated target in chloroform by using a previously described dry distillation procedure.[3] All other reagents were commercially available and used as received unless otherwise noted.

Analysis: Radioactivity was quantified using a dose curiemeter IGC-7R, Aloka. Reversed-phase high-performance liquid chromatography (HPLC) was performed on a JASCO LC-2000Plus series PU-2089i gradient pump equipped with a JASCO UV-2075 UV detector and a Universal Giken US-3000 radiation detector. Thin layer chromatography (TLC) was carried out on Merck KGaA F_{254} plates and analyzed on a M&S Instruments Marita Star detector with GINA Star TLC Software.

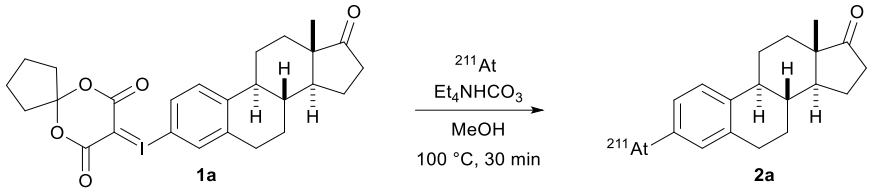
2. Confirmation of the identity of ^{211}At-labeled compounds

Synthesis of an authentic sample 2a via electrophilic astatodestannylation of arylstannane S1



To a V-shaped glass vial was added a solution of ^{211}At (8.9 MBq) in $CHCl_3$, and then the solvent was evaporated with the gentle flow of N_2 gas at 100 °C. Subsequently, a solution of arylstannane **S1**[4] (2 mg) in MeOH/AcOH = 1000:1 (50 μL) and a solution of NCS (4 mg) in MeOH (10 μL) were added to the residue. After the reaction at room temperature for 15 min, the reaction mixture was analyzed by radio-HPLC.

The reaction of aryliodonium ylide 1a with ^{211}At$^-$



To a V-shaped glass vial was added a solution of ^{211}At (52 MBq) in $CHCl_3$, and then the solvent was evaporated with the gentle flow of N_2 gas at 100 °C. The residue was dissolved in MeOH (30 μL), followed by the addition of a mixture of aryliodonium ylide **1a** (2 mg) and Et_4NHCO_3 (7 mg) in MeOH (70 μL), which is not fully optimized reaction conditions. After the reaction at 100 °C for 30 min, the reaction mixture was analyzed by radio-HPLC.

HPLC conditions and chromatograms

HPLC analysis was performed on InertSustain C18 (150×4.6 mm, 5 μm) column with flow rate at 1.0 mL/min using 30% H_2O (0.1% HCOOH)/70% MeCN eluent. The injected sample initially passed through the UV detector, followed by the radiation detector, which cause a slight delay between the corresponding UV and radiation peaks. For each analysis, a corresponding non-radioactive I-labeled compound was used as a UV reference. Due to the chemical similarities of iodine and astatine, the difference of retention time between the I-labeled compound and the ^{211}At-labeled compound would be small. The resulting HPLC chromatograms were shown in below (Figure S1).

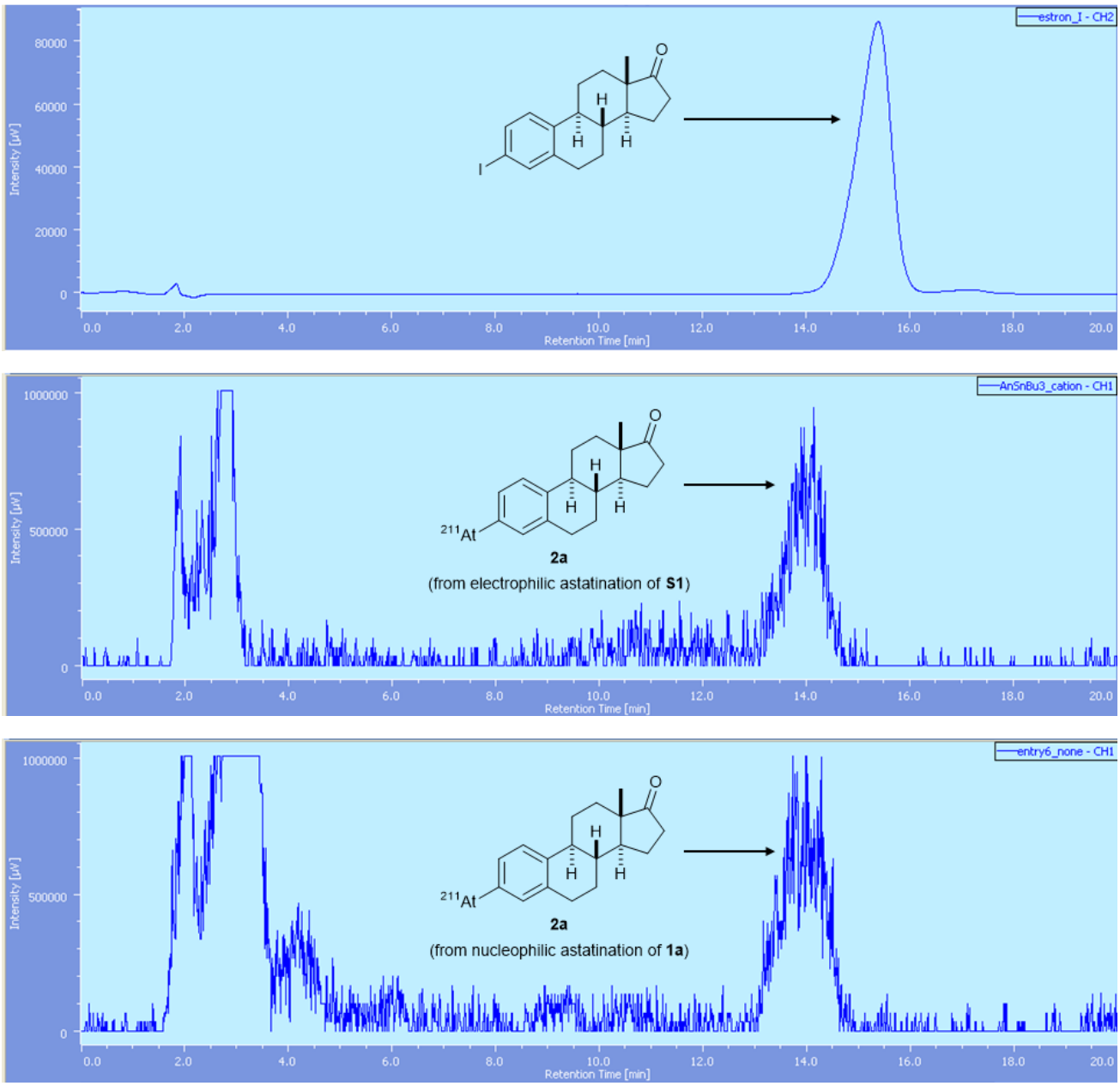
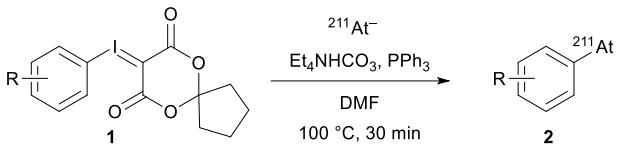


Figure S1. UV-HPLC chromatogram of I-labeled standard (top), radio-HPLC chromatogram of the electrophilic astatination of **S1** (middle), radio-HPLC chromatogram of the nucleophilic astatination of **1a** (bottom)

In the radio-HPLC chromatogram of each reaction, the same radiation peaks were observed at 13.0 to 15.0 min, respectively. In the adjacent to these radiation peaks, the UV peak of I-labeled standard was observed at 14.0 to 16.0 min. These results indicate that these radiation peaks at 13.0 min to 15.0 min would be ^{211}At-labeled compound **2a**. Therefore, we have concluded that the reaction of aryliodonium ylide **1a** with $^{211}At^{-}$ would afford ^{211}At-labeled compound **2a**.

3. ^{211}At-astatination of aryliodonium ylide with $^{211}At^-$

General procedure for ^{211}At-astatination of aryliodonium ylide



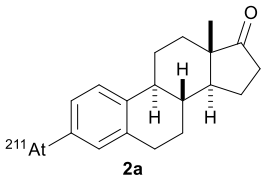
To a V-shaped glass vial was added a solution of ^{211}At (16-43 MBq) in $CHCl_3$, followed by removal of the solvent at 100 °C with the gentle flow of N_2 gas. Then, a solution of aryliodonium ylide **1** (10 mg) in DMF (300 μL), a solution of Et_4NHCO_3 (7 mg) in DMF (100 μL), and a solution of PPh_3 (5 mg) in DMF (100 μL) were successively added to the residue. After the reaction at 100 °C for 30 min under nitrogen atmosphere, the reaction mixture was directly analyzed by radio-HPLC and radio-thin-layer chromatography.

General methods for analysis of ^{211}At-astatination reactions

The identity of ^{211}At-labeled compound **2** was confirmed by radio-HPLC. Reversed-phase HPLC analysis was performed on InertSustain C18 (150×4.6 mm, 5 μm) column with flow rate at 1.0 mL/min using H_2O (0.1% HCOOH)/MeCN eluent. The eluent was changed in response to the product polarity. The injected sample initially passed through the UV detector, followed by the radiation detector, which cause a slight delay between the corresponding UV and radiation peaks.

In the HPLC analysis, the adsorption of unlabeled $^{211}At^-$ on the column has often become a problem for the calculation of radiochemical yields (RCYs).[5] Furthermore, insufficient sensitivity of our radiation detector led to an insufficient signal-noise ratio of the analysis. For these reasons, RCYs were calculated as peak area of compound **2**/total×100% on radio-TLC analysis. The decay of radioactivity during the reaction has not been considered for the calculation of RCYs since the reaction time was only 30 minutes, which was enough short compared with the half-life of ^{211}At (7.2 h). Appropriate solvent conditions were determined to separate the free $^{211}At^-$ (Rf = 0.00-0.25) from the target radiolabeled compounds **2**. For each analysis, corresponding non-radioactive I-labeled compound was used as references due to the chemical similarities of iodine and astatine.

(*8R,9S,13S,14S*)-3-[^{211}At]astato-13-methyl-6,7,8,9,11,12,13,14,15,16-decahydro-17*H*-cyclopenta[a]phenanthren-17-one (2a)



2a

According to the general procedure, the reaction of 8-(((*8R,9S,13S,14S*)-13-methyl-17-oxo-7,8,9,11,12,13,14,15,16,17-decahydro-6*H*-cyclopenta[a]phenanthren-3-yl)-λ^3-iodanylidene)-6,10-dioxaspiro[4.5]decane-7,9-dione **1a** with $^{211}At^-$ (43 MBq) afforded **2a** in 58% RCY.

Radio-TLC chromatography

Development solvent: hexane/ethyl acetate = 5:1

Retention factor of the corresponding non-radioactive I-labeled compound: 0.35

Retention factor of ^{211}At-labeled **2a**: 0.31

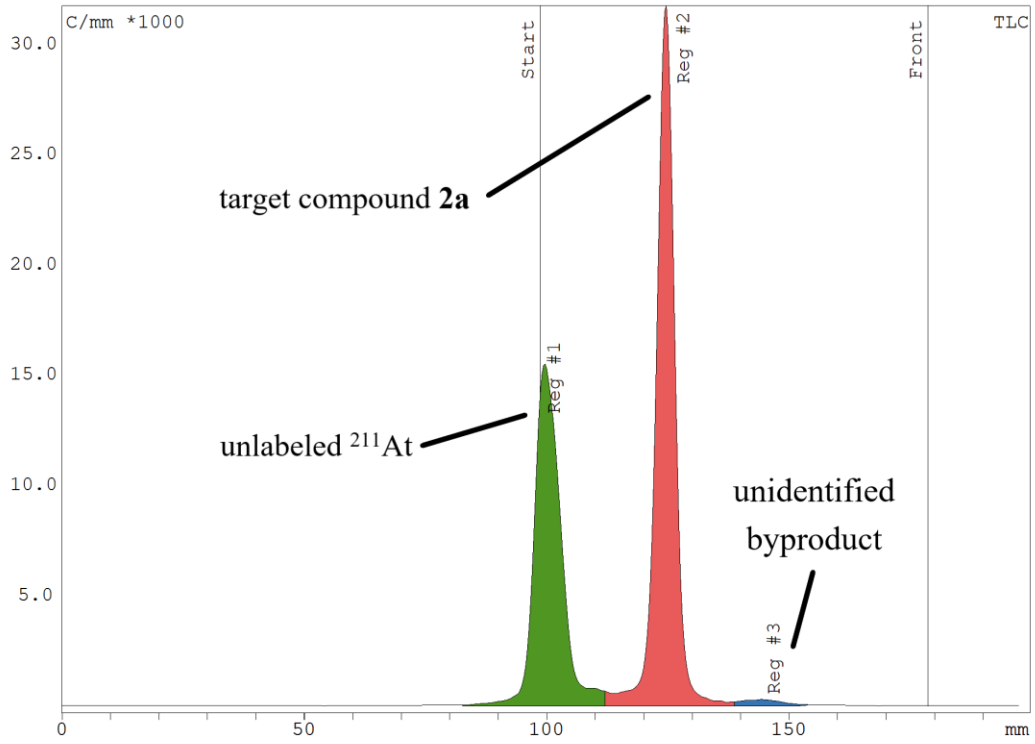
The trace amount of the least polar material (Rf = 0.55 highlighted in blue) is an unidentified byproduct.

Radio-HPLC chromatography

Eluent: 30% H_2O (0.1% HCOOH)/70% MeCN

Retention time of the corresponding non-radioactive I-labeled compound: 14.0-16.0 min

Retention time of radioactive ^{211}At-labeled **2a**: 13.0-15.0 min



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Method: Hokudai from: 2000/01/01
Origin: 100 mm Front 180 mm
Meas. time: 1.0 min Resolution: 0.3 mm

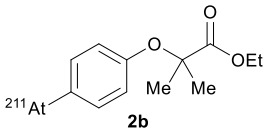
km07144 positive
Radio detector: raytest Ramona-92 Serial Nr.: 0

TLC

Substance	R/F	%Total	Type	Area	%Area
		%		Counts	%
Reg #1	-0.004	40.40	DD	99878.0	40.79
Reg #2	0.308	57.49	DD	142106.0	58.04
Reg #3	0.550	1.15	DD	2855.0	1.17
Sum in ROI				244839.0	
Total area				247195.0	
Area RF				201859.0	

Figure S2. The result of radio-TLC analysis in the crude mixture of **2a**

ethyl 2-[^{211}At](4-astatophenoxy)-2-methylpropanoate (2b)



2b

According to the general procedure, the reaction of ethyl 2-(4-((7,9-dioxo-6,10-dioxaspiro[4.5]decan-8-ylidene)-λ^3-iodanyl)phenoxy)-2-methylpropanoate **1b** with $^{211}At^-$ (34 MBq) afforded **2b** in 63% RCY.

Radio-TLC chromatography

Development solvent: hexane/ethyl acetate = 8:1

Retention factor of the corresponding non-radioactive I-labeled compound: 0.45

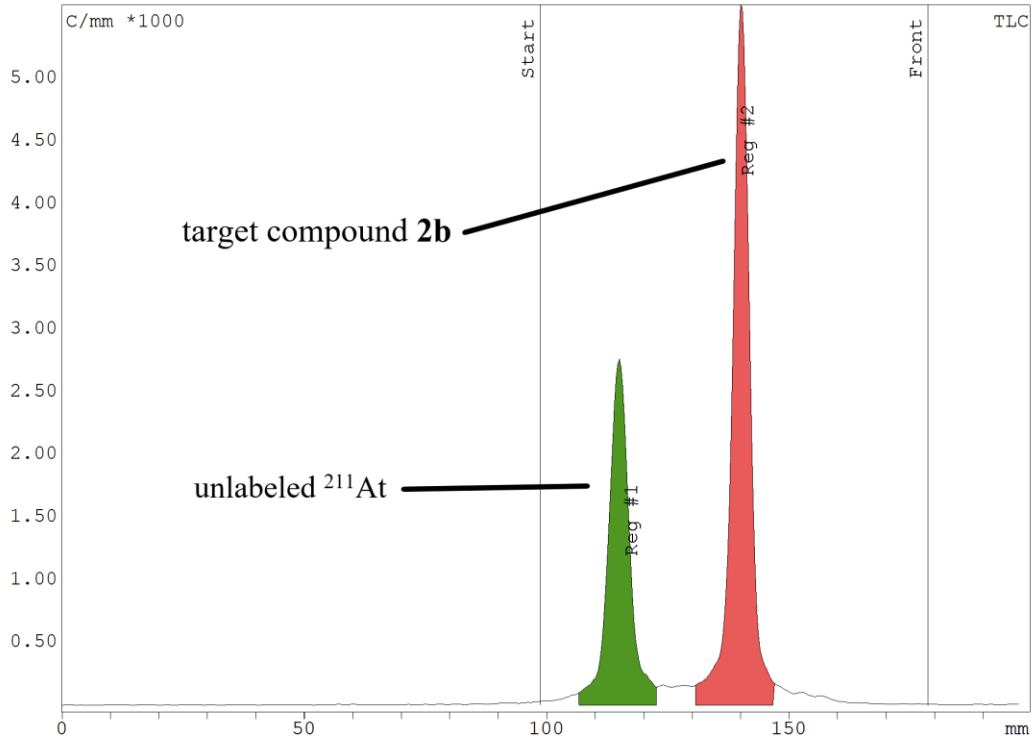
Retention factor of ^{211}At-labeled **2b**: 0.50

Radio-HPLC chromatography

Eluent: 40% H_2O (0.1% HCOOH)/60% MeCN

Retention time of the corresponding non-radioactive I-labeled compound: 13.8-15.2 min

Retention time of radioactive ^{211}At-labeled **2b**: 12.2-13.6 min



Measurement: 20200128-06-clofibrate.rta, started: 2020/01/28 20:42
Method: Hokudai
Origin: 100 mm Front 180 mm
Meas. time: 1.0 min Resolution: 0.3 mm
High voltage: 1626.0 V
Radio detector: Serial Nr.: 0

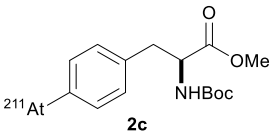
TLC

Substance	R/F	%Total	Type	Area	%Area
		%		Counts	%
Reg #1	0.188	33.40	DD	13884.00	36.81
Reg #2	0.500	57.34	DD	23832.00	63.19
Sum in ROI				37716.00	
Total area				41566.00	
Area RF				41032.00	

Figure S3. The result of radio-TLC analysis in the crude mixture of **2b**

methyl (*S*)-3-[^{211}At](4-astatophenyl)-2-((*tert*-butoxycarbonyl)amino)propanoate (2c)

According to the general procedure, the reaction of methyl (*S*)-2-((*tert*-butoxycarbonyl)amino)-3-(4-((7,9-dioxo-6,10-dioxaspiro[4.5]decan-8-ylidene)-λ^3-iodanyl)phenyl)propanoate **1c** with $^{211}At^-$ (16 MBq) afforded **2c** in 69% RCY.



2c

Radio-TLC chromatography

Development solvent: hexane/ethyl acetate = 3:1

Retention factor of the corresponding non-radioactive I-labeled compound: 0.33

Retention factor of ^{211}At-labeled **2c**: 0.45

The trace amount of the least polar material (Rf = 0.73 highlighted in blue) is an unidentified byproduct.

Radio-HPLC chromatography

Eluent: 45% H_2O (0.1% HCOOH)/55% MeCN

Retention time of the corresponding non-radioactive I-labeled compound: 14.8-16.2 min

Retention time of radioactive ^{211}At-labeled **2c**: 11.6-12.8 min

Measurement 20190829entry5-phe.rta raytest GmbH Page 1/1
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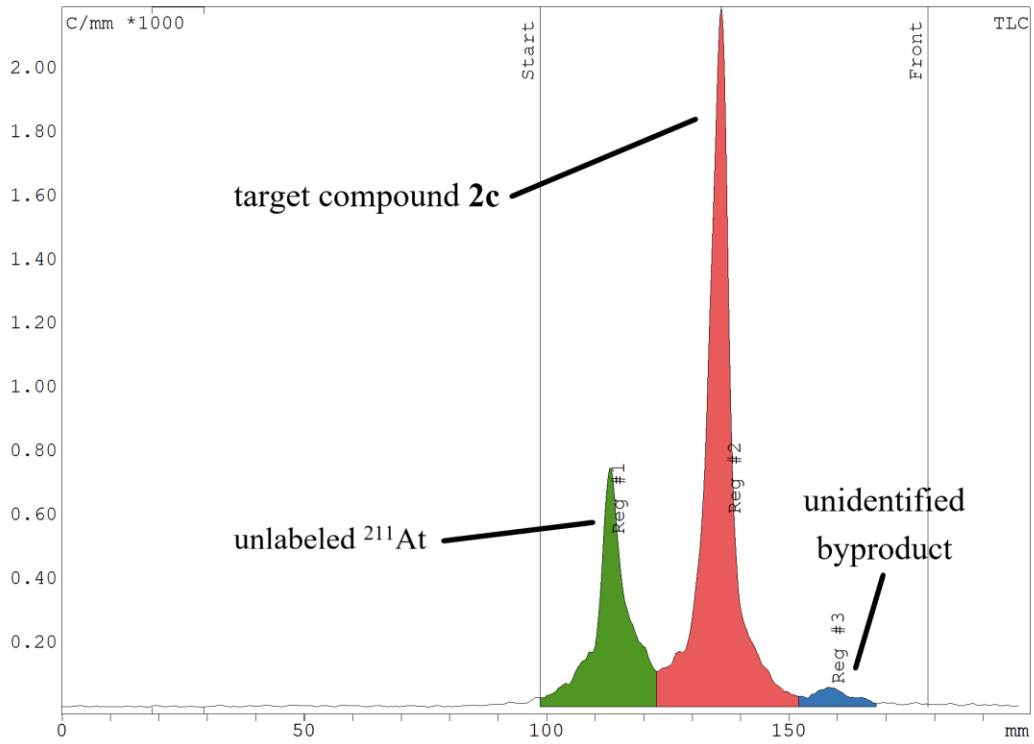


Measurement: 20190829entry5-phe.rta, started: 2019/08/29 20:14
Method: Hokudai from: 2000/01/01
Origin: 100 mm Front 180 mm
Meas. time: 1.0 min Resolution: 0.3 mm
Radio detector: raytest Ramona-92 Serial Nr.: 0

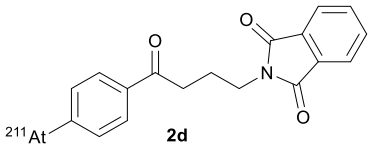
TLC

Substance	R/F	%Total	Type	Area	%Area
		%		Counts	%
Reg #1	0.167	26.74	DD	5398.22	27.84
Reg #2	0.450	66.62	DD	13446.22	69.34
Reg #3	0.733	2.71	DD	547.30	2.82
Sum in ROI				19391.74	
Total area				20184.41	
Area RF				19648.00	
BKG1				1.444	
Remainder RF				256.26	1.30
Remainder (Tot)				792.67	3.93

Figure S4. The result of radio-TLC analysis in the crude mixture of **2c**

2-[^{211}At](4-(4-astatophenyl)-4-oxobutyl)isoindoline-1,3-dione (2d)

According to the general procedure, the reaction of 2-(4-(4-((7,9-dioxo-6,10-dioxaspiro[4.5]decan-8-ylidene)-λ^3-iodanyl)phenyl)-4-oxobutyl)isoindoline-1,3-dione **1d** with $^{211}At^-$ (16 MBq) afforded **2d** in over 99.5% RCY.



2d

Radio-TLC chromatography

Development solvent: hexane/ethyl acetate = 3:1

Retention factor of the corresponding non-radioactive I-labeled compound: 0.25

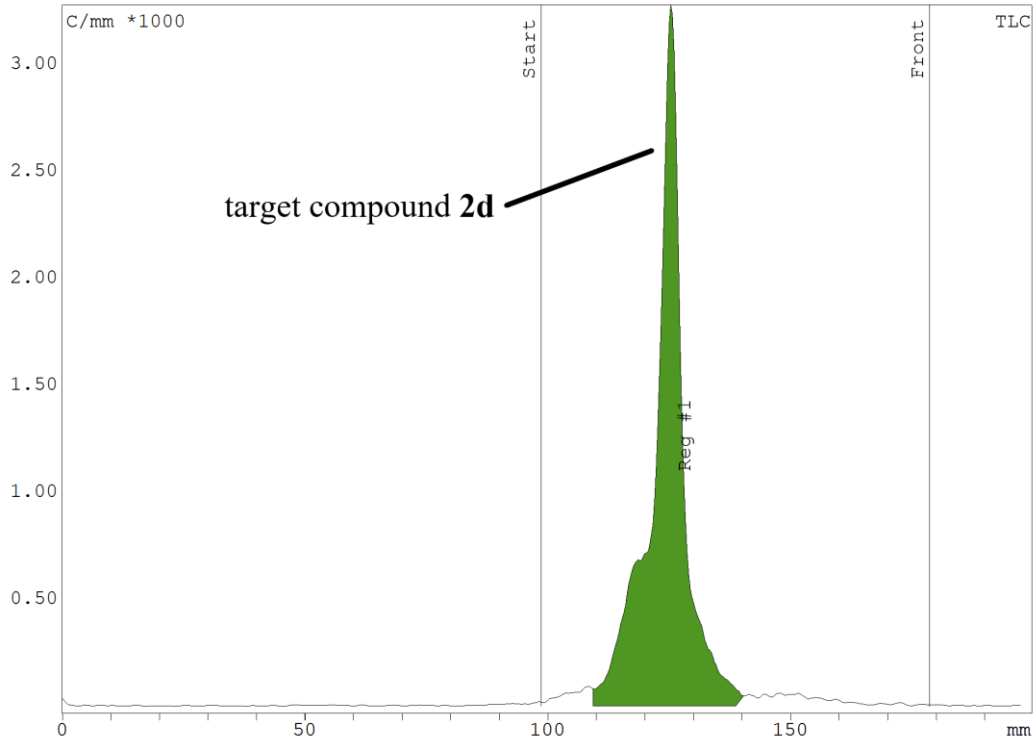
Retention factor of ^{211}At-labeled **2d**: 0.32

Radio-HPLC chromatography

Eluent: 45% H_2O (0.1% HCOOH)/55% MeCN

Retention time of the corresponding non-radioactive I-labeled compound: 13.5-14.7 min

Retention time of radioactive ^{211}At-labeled **2d**: 7.6-13.0 min



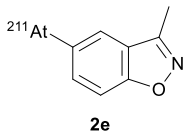
Measurement: 20190829entry4-butyro.rta, started: 2019/08/29 20:18
Method: Hokudai from: 2000/01/01
Origin: 100 mm Front 180 mm
Meas. time: 1.0 min Resolution: 0.3 mm
Radio detector: raytest Ramona-92 Serial Nr.: 0

TLC

Substance	R/F	%Total	Type	Area	%Area
		%		Counts	%
Reg #1	0.317	90.96	DD	22275.00	100.00
Sum in ROI				22275.00	
Total area				24490.00	
Area RF				24012.00	

Figure S5. The result of radio-TLC analysis in the crude mixture of **2d**

5-[^{211}At]astato-3-methylbenzo[d]isoxazole (2e)



2e

According to the general procedure, the reaction of 8-((3-methylbenzo[d]isoxazol-5-yl)-λ^3-iodanylidene)-6,10-dioxaspiro[4.5]decane-7,9-dione **1e** with $^{211}At^-$ (28 MBq) afforded **2e** in 92% RCY.

Radio-TLC chromatography

Development solvent: hexane/ethyl acetate = 8:1

Retention factor of the corresponding non-radioactive I-labeled compound: 0.42

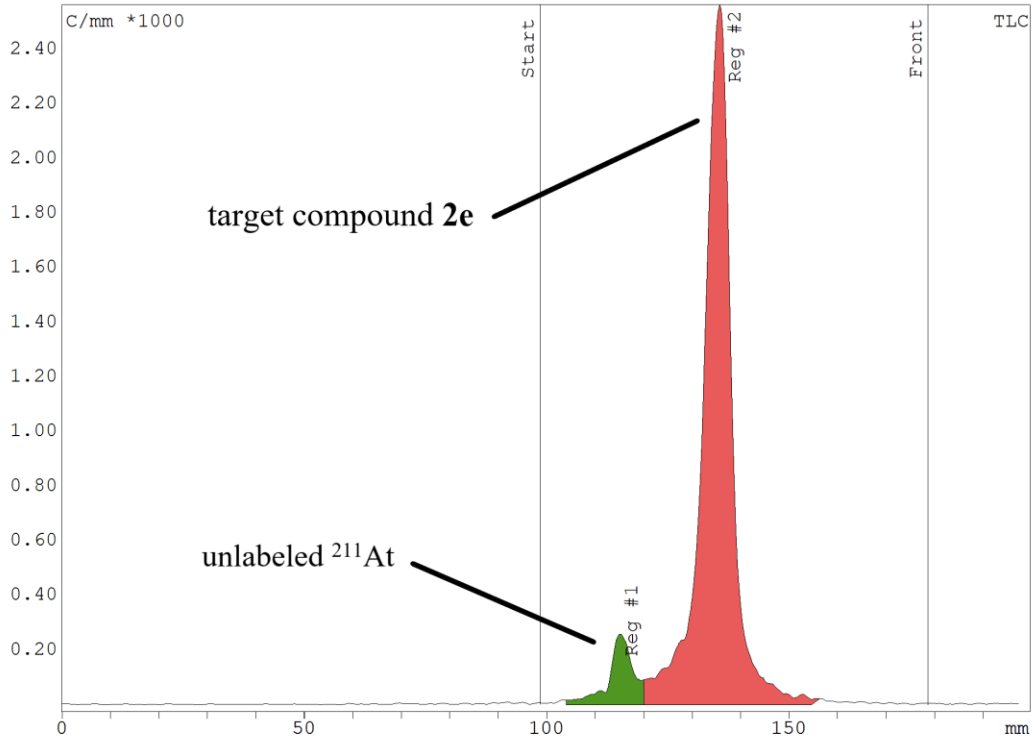
Retention factor of ^{211}At-labeled **2e**: 0.45

Radio-HPLC chromatography

Eluent: 55% H_2O (0.1% HCOOH)/45% MeCN

Retention time of the corresponding non-radioactive I-labeled compound: 16.4-17.8 min

Retention time of radioactive ^{211}At-labeled **2e**: 14.8-16.6 min



Measurement: 20200128-07-risperidone.rta, started:2020/01/28 22:11
Method: Hokudai from: 2000/01/01
Origin: 100 mm Front 180 mm
Meas. time: 1.0 min Resolution: 0.3 mm
Radio detector: raytest Ramona-92 Serial Nr.: 0

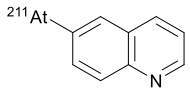
TLC

Substance	R/F	%Total	Type	Area	%Area
		%		Counts	%
Reg #1	0.188	8.14	DD	1600.00	8.35
Reg #2	0.446	89.37	DD	17564.00	91.65
Sum in ROI				19164.00	
Total area				19653.00	
Area RF				19395.00	

Figure S6. The result of radio-TLC analysis in the crude mixture of **2e**

6-[^{211}At]astatoquinoline (2f)

According to the general procedure, the reaction of 8-(quinolin-6-yl-λ^3-iodanylidene)-6,10-dioxaspiro[4.5]decane-7,9-dione **1f** with $^{211}At^-$ (24 MBq) afforded **2f** in over 99.5% RCY.



2f

Radio-TLC chromatography

Development solvent: hexane/ethyl acetate = 1:1

Retention factor of the corresponding non-radioactive I-labeled compound: 0.38

Retention factor of ^{211}At-labeled **2f**: 0.50

Radio-HPLC chromatography

Eluent: 70% H_2O (0.1% HCOOH)/30% MeCN

Retention time of the corresponding non-radioactive I-labeled compound: 11.0-13.0 min

Retention time of radioactive ^{211}At-labeled **2f**: 6.8-7.8 min

Different basicity of nitrogen atom on iodinated or astatinated quinolines might affect their retention time in the acidic eluent.

Measurement 20200128-01-quinoline.rta raytest GmbH Page 1/1
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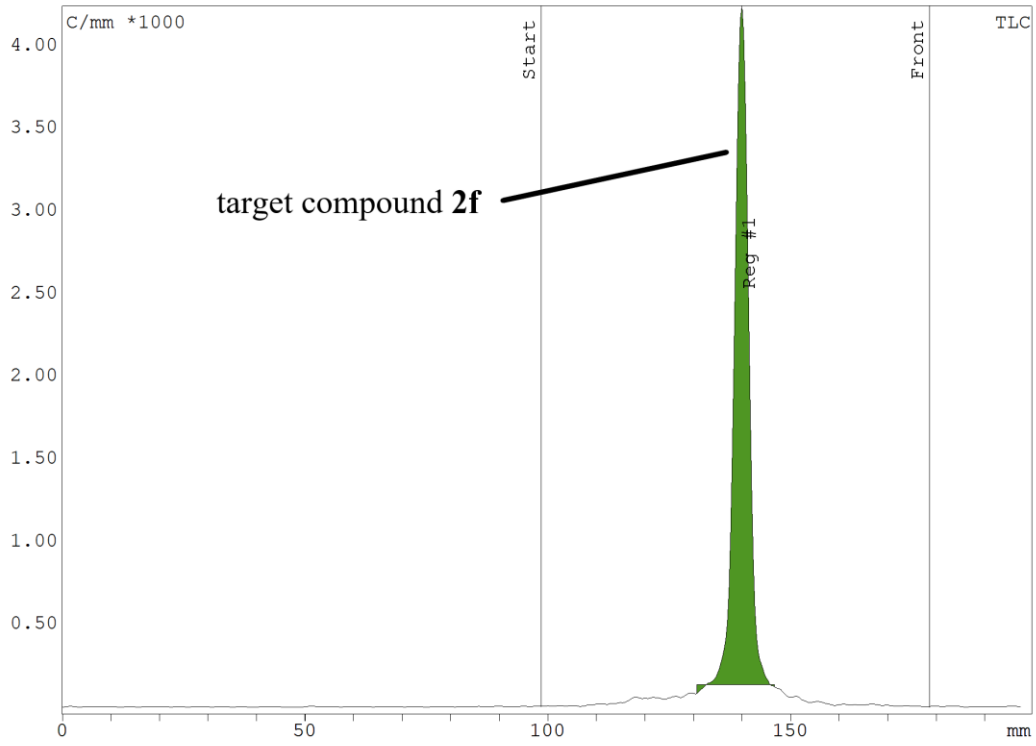


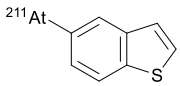
Measurement: 20200128-01-quinoline.rta, started: 2020/01/28 15:34
Method: Hokudai
Origin: 100 mm Front 180 mm
Meas. time: 1.0 min Resolution: 0.3 mm
High voltage: 1626.0 V
Radio detector: Serial Nr.: 0

TLC

Substance	R/F	%Total	Type	Area	%Area
		%		Counts	%
Reg #1	0.500	76.86	BB	13901.39	100.00
Sum in ROI				13901.39	
Total area				18086.00	
Area RF				17889.00	

Figure S7. The result of radio-TLC analysis in the crude mixture of **2f**

5-[^{211}At]astatobenzo[b]thiophene (2g)



2g

According to the general procedure, the reaction of 8-(benzo[b]thiophen-5-yl-λ^3-iodanylidene)-6,10-dioxaspiro[4.5]decane-7,9-dione **1g** with $^{211}At^-$ (31 MBq) afforded **2g** in 93% RCY.

Radio-TLC chromatography

Development solvent: hexane

Retention factor of the corresponding non-radioactive I-labeled compound: 0.51

Retention factor of ^{211}At-labeled **2g**: 0.43

Radio-HPLC chromatography

Eluent: 40% H_2O (0.1% HCOOH)/60% MeCN

Retention time of the corresponding non-radioactive I-labeled compound: 13.4-14.6 min

Retention time of radioactive ^{211}At-labeled **2g**: 14.2-16.0 min

Measurement 20200128-05-benzothiophen.rta raytest GmbH Page 1/1
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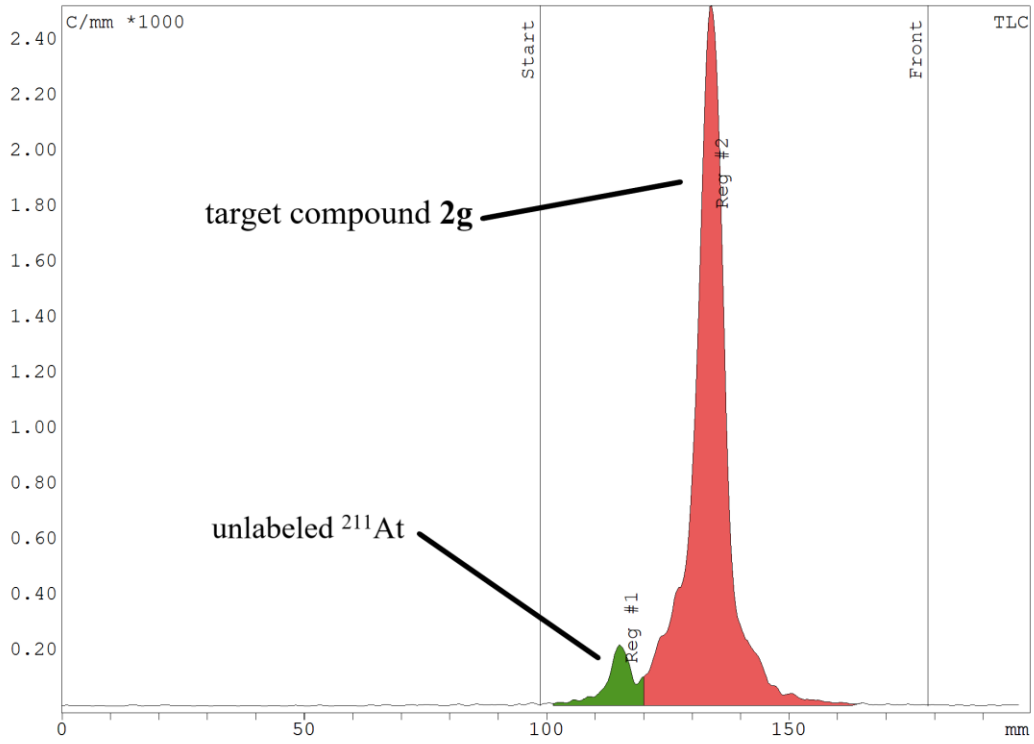


Measurement: 20200128-05-benzothiophen.rta, started: 2020/01/28 19:
Method: Hokudai from: 2000/01/01
Origin: 100 mm Front 180 mm
Meas. time: 1.0 min Resolution: 0.3 mm
Radio detector: raytest Ramona-92 Serial Nr.: 0

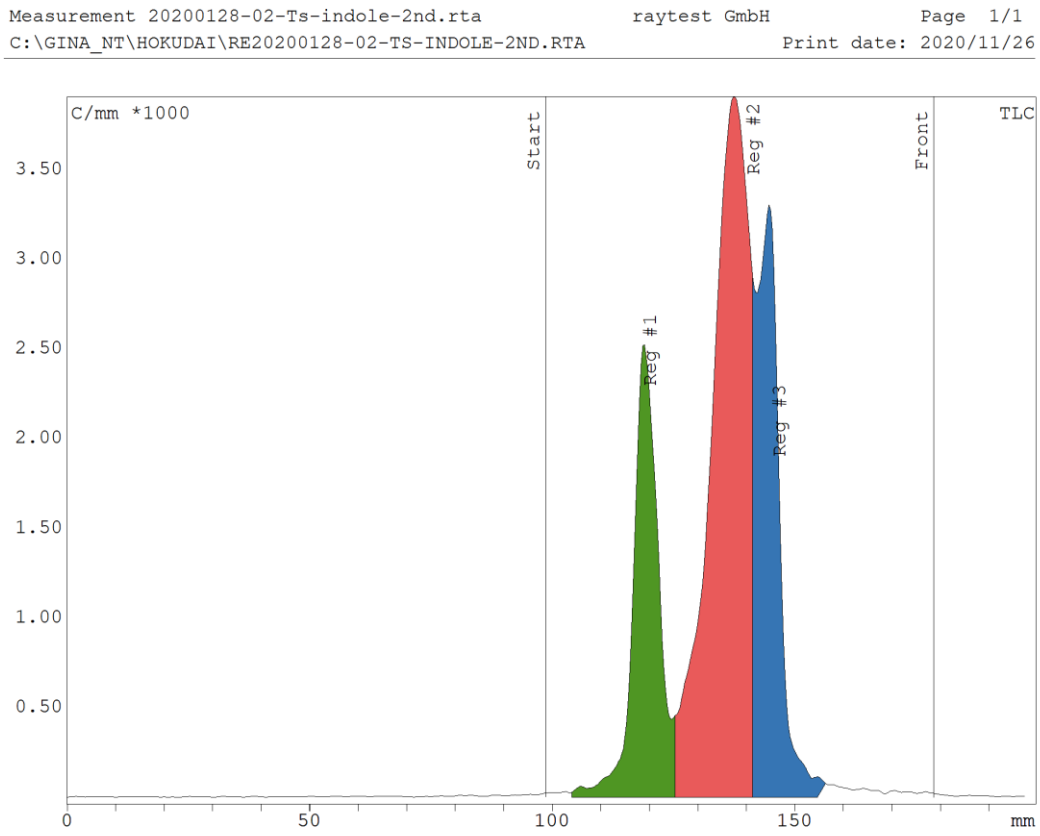
TLC

Substance	R/F	%Total	Type	Area	%Area
		%		Counts	%
Reg #1	0.188	6.49	DD	1376.00	6.59
Reg #2	0.425	92.04	DD	19503.00	93.41
Sum in ROI				20879.00	
Total area				21189.00	
Area RF				20961.00	

Figure S8. The result of radio-TLC analysis in the crude mixture of **2g**

4. ^{211}At-astatination of indolyliodonium ylide

According to the general procedure, 8-((1-tosyl-1*H*-indol-5-yl)-λ^3-iodanylidene)-6,10-dioxaspiro[4.5]decane-7,9-dione **5** was reacted with $^{211}At^-$ (33 MBq), Et_4NHCO_3, and PPh_3 in DMF at 100 °C for 30 min. The reaction mixture was analysed by radio-TLC, and the result is shown in below (Figure S9).



Measurement: 20200128-02-Ts-indole-2nd.rta, started: 2020/01/28 16:
Method: Hokudai from: 2000/01/01
Origin: 100 mm Front 180 mm
Meas. time: 1.0 min Resolution: 0.3 mm
Radio detector: raytest Ramona-92 Serial Nr.: 0

TLC

Substance	R/F	%Total	Type	Area	%Area
		%		Counts	%
Reg #1	0.238	21.88	DD	15541.00	22.37
Reg #2	0.471	58.22	DD	41358.00	59.54
Reg #3	0.558	17.68	DD	12560.00	18.08
Sum in ROI				69459.00	
Total area				71041.00	
Area RF				70485.00	

Figure S9. The result of radio-TLC analysis in the reaction of **5** with $^{211}At^{-}$

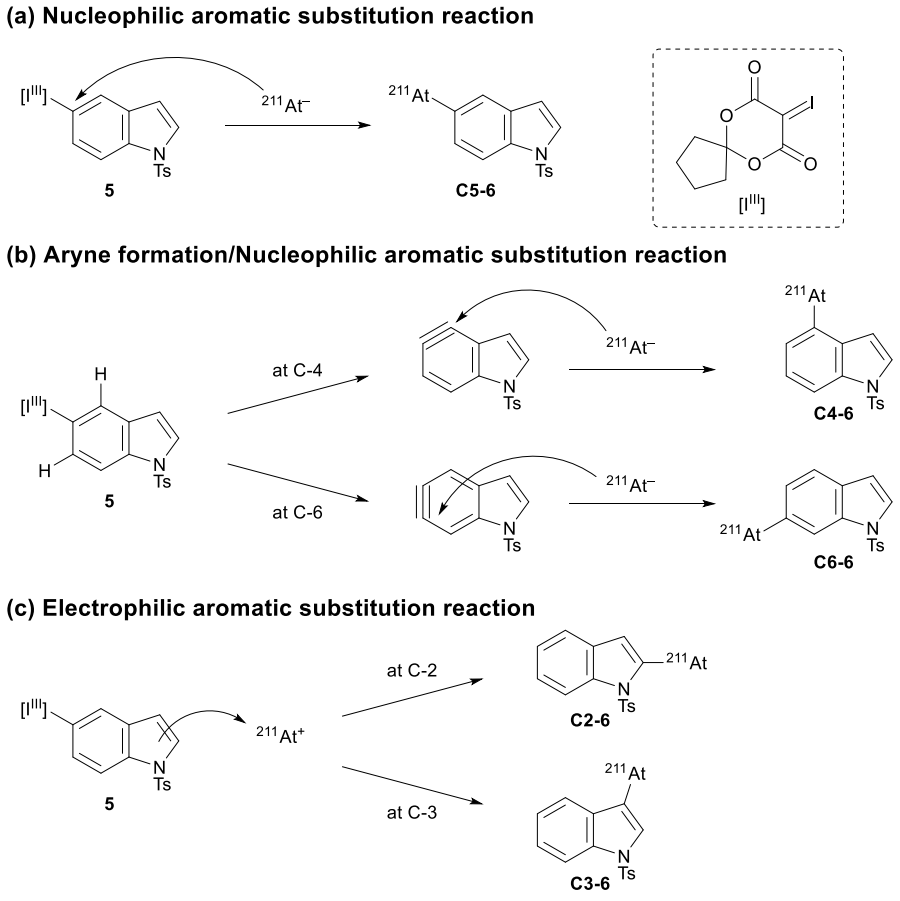
Development solvent: hexane/ethyl acetate = 8:1 (developed twice)

Retention factor of the corresponding non-radioactive I-labeled compound: 0.42

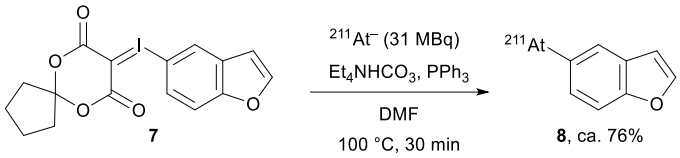
On the TLC plate, different three peaks were observed as the major materials (Rf = 0.24, 0.47, 0.56). The most polar material (Rf = 0.24 highlighted in green) would be unlabeled $^{211}At^{-}$. The others with similar polarity (Rf = 0.47 highlighted in red, and Rf = 0.56 highlighted in blue) were positioned near the corresponding non-

radioactive *N*-Ts-5-[^{127}I]iodoindole (Rf = 0.42). These results indicated that these two radioactive materials would be regioisomers of ^{211}At-labeled indole **6**. We propose the following three pathways to afford the regioisomers **6**. First, nucleophilic aromatic substitution reaction of **5** would proceed to afford 5-[^{211}At]astatoindole (**C5-6**) (Scheme S1a). As a second pathway, the aryne formation would initially occur, and then $^{211}At^-$ attacked the aryne to afford C-4 or C-6 labeled compounds (**C4-** or **C6-6**) (Scheme S1b). The formation of aryne from aryliodonium ylide has also been reported in a radiofluorination reaction.[6] In this report, an electron-rich arene is more likely to form the aryne and converted to the mixture of ^{18}F-labeled regioisomers. As the other pathway, an electrophilic aromatic substitution reaction at C-2 or C-3 position of indole **5** with $^{211}At^+$ and decomposition of iodonium ylide might proceed to afford ^{211}At-labeled compounds (**C2-** or **C3-6**) (Scheme S1c). Although the reaction was performed under reducing conditions, the possibility that $^{211}At^-$ was oxidized to $^{211}At^+$ cannot be fully excluded.

Scheme S1. Plausible pathways to afford regioisomers **6**



5. ^{211}At-astatination of benzofuryliodonium ylide



According to the general procedure, 8-(benzofuran-5-yl-λ^3-iodanylidene)-6,10-dioxaspiro[4.5]decane-7,9-dione **7** was reacted with ^{211}At$^-$ (31 MBq), Et_4NHCO_3, and PPh_3 in DMF at 100 °C for 30 min. The reaction mixture was analyzed by radio-TLC and radio-HPLC. These results are shown in below (Figure S10, 11).

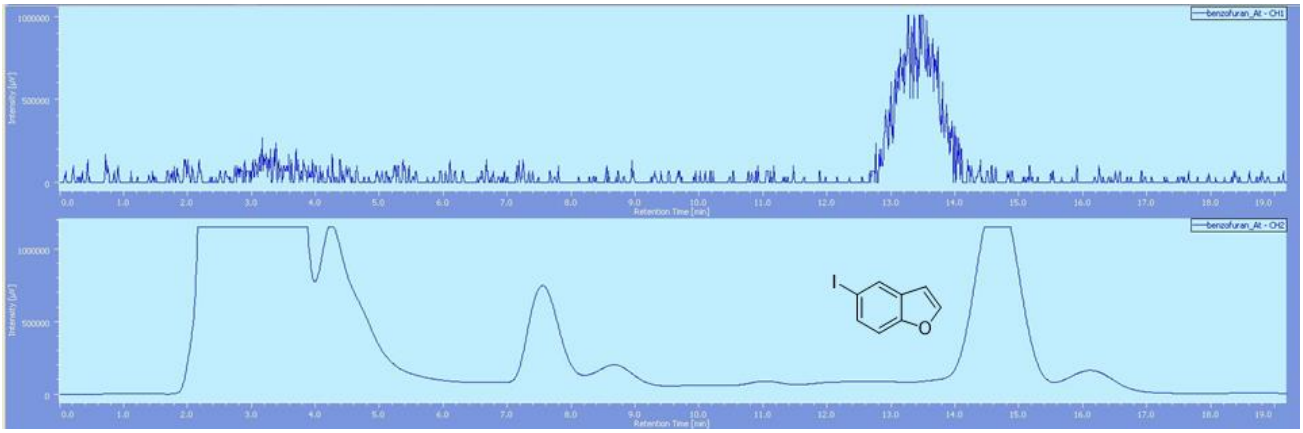
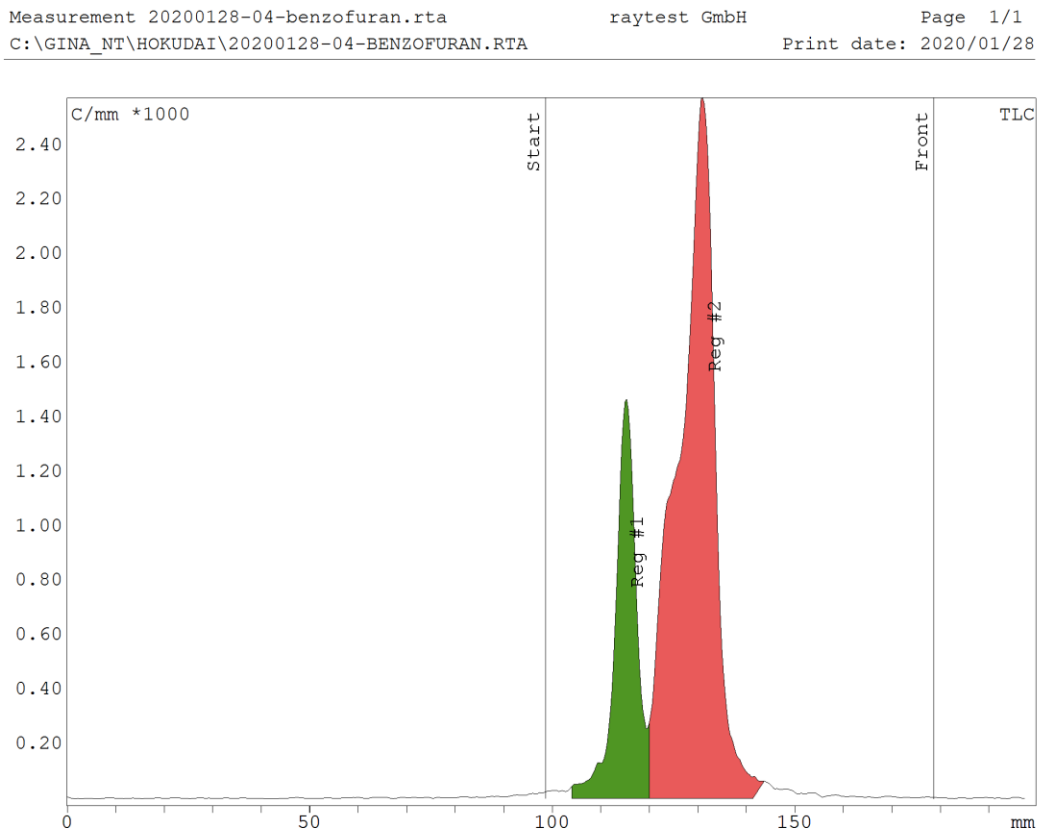


Figure S10. Radio-HPLC (top) and UV-HPLC (bottom) chromatogram of the reaction mixture of **7** with ^{211}At$^-$
Eluent: 45% H_2O (0.1% HCOOH)/55% MeCN
Retention time of the corresponding non-radioactive I-labeled compound: 13.8-15.6 min



Measurement: 20200128-04-benzofuran.rta, started: 2020/01/28 18:15
Method: Hokudai
Origin: 100 mm Front 180 mm
Meas. time: 1.0 min Resolution: 0.3 mm
High voltage: 1626.0 V
Radio detector: Serial Nr.: 0

TLC

Substance	R/F	%Total	Type	Area	%Area
		%		Counts	%
Reg #1	0.192	23.45	DD	7280.00	24.39
Reg #2	0.388	72.69	DD	22570.00	75.61
Sum in ROI				29850.00	
Total area				31049.00	
Area RF				30610.00	

Figure S11. The result of radio-TLC analysis in the reaction of **7** with $^{211}At^{-}$

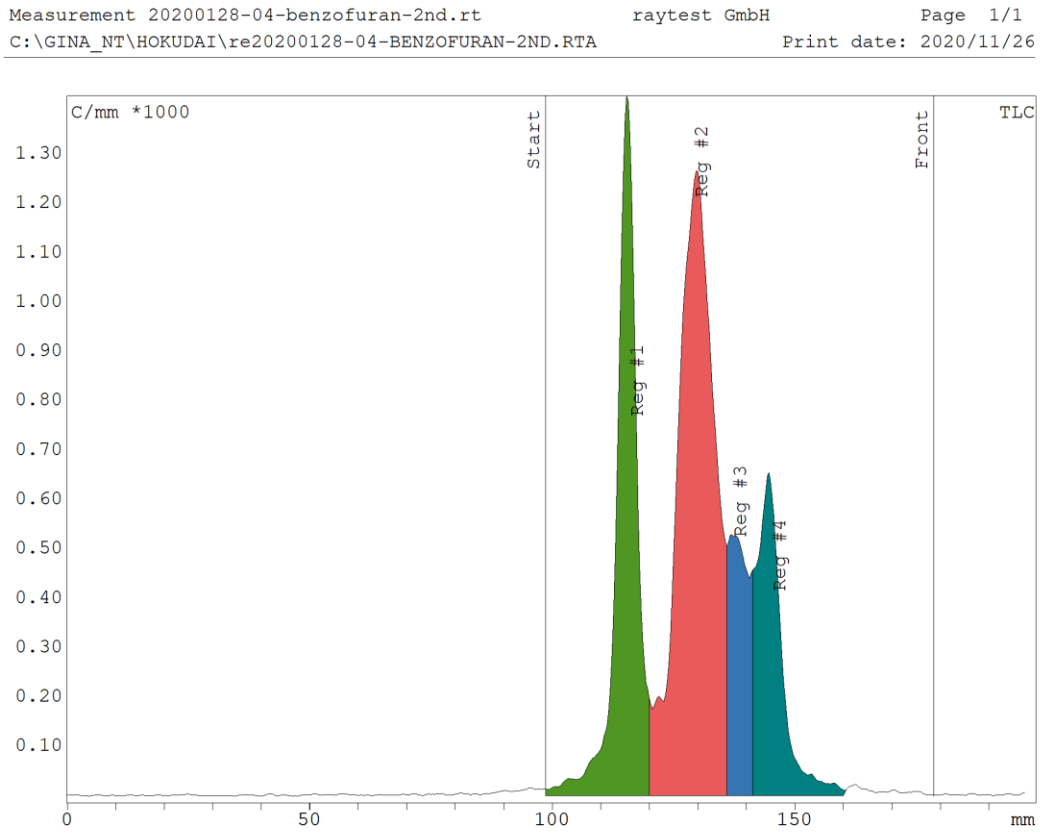
Development solvent: hexane

Retention factor of corresponding non-radioactive I-labeled compound: 0.46

On the TLC plate, two peaks were observed as major materials (Rf = 0.19, 0.39). The more polar material (Rf = 0.19 highlighted in green) would be unlabeled $^{211}At^{-}$. Although peak tailing occurred, the other (Rf = 0.39 highlighted in red) was close to the corresponding non-radioactive 5-[^{127}I]iodobenzofuran (Rf = 0.46). In the HPLC chromatogram, the radiation peak (retention time: 12.8-14.2 min) was also observed close to the UV

peak of the I-labeled standard. These analyses ensure that the reaction of **7** with $^{211}At^{-}$ afforded ^{211}At-labeled benzofuran **8** in ca. 76% RCY.

To examine the identity of peak tailing on the radio-TLC analysis, we developed the same TLC plate again, and the resulting image of radio-TLC analysis is shown in below (Figure S12).



Measurement: 20200128-04-benzofuran-2nd.rt, started: 2020/01/28 18:
Method: Hokudai from: 2000/01/01
Origin: 100 mm Front 180 mm
Meas. time: 1.0 min Resolution: 0.3 mm
Radio detector: raytest Ramona-92 Serial Nr.: 0

TLC

Substance	R/F	%Total	Type	Area	%Area
		%		Counts	%
Reg #1	0.192	27.62	DD	6908.00	28.21
Reg #2	0.371	45.22	DD	11310.00	46.19
Reg #3	0.467	9.23	DD	2309.00	9.43
Reg #4	0.558	15.82	DD	3957.00	16.16
Sum in ROI				24484.00	
Total area				25010.00	
Area RF				24674.00	

Figure S12. The result of radio-TLC analysis in the reaction of **7** with $^{211}At^{-}$ (developed twice)
Development solvent: hexane (developed twice)

In the first TLC, the peak tailing was observed (Rf = 0.39 highlighted in red), which suggested that the less polar peak was the major product and the more polar peak was the minor product (**Figure S11**). However, in the second TLC, in which several radiation peaks were observed, the less polar peaks were minor products (Rf = 0.47 highlighted in red, and Rf = 0.56 highlighted in dark green) and the more polar peak was the major product (Rf = 0.37 highlighted in red) (**Figure S12**). If the peak tailing in the first TLC had been due to only the overlapped peaks, the less polar peak would have become the major product and the more polar peak would have become the minor product in the second TLC. These results indicate that the behavior of the compounds were different in the first and second development on the TLC plate. We consider that the less polar ^{211}At-labeled benzofuran **8** would be unstable on the silica gel and decomposed into the more polar compounds on the TLC plate.

6. Supplementary references

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