RhoGEF Exchange Assay Biochem Kit

Cat. # BK100

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I: Introduction

The Ras superfamily of small GTPases consist of more than 150 members, which based on their sequence homology, are divided into several subfamilies such as Rho, Ras, Ran, Rab, Arf and Rem/Rad families. This group of small GTPases serve as binary switches cycling between GDP-bound inactive and GTP-bound active states (1,2). The regulatory proteins for this switch include guanine nucleotide exchange factors (GEFs), GTPase activating proteins (GAPs) and guanine nucleotide dissociation inhibitors (GDIs) (1,2).

GEFs catalyze the exchange of GDP for GTP to generate the active state of small GTPases in response to extracellular signals. In order to facilitate the exchange, the GEFs must bind to the GDP-bound GTPases, destabilize the GDP-GTPase complex, and then stabilize a nucleotide-free reaction intermediate. Because of the high intracellular ratio of GTP to GDP, the released GDP is replaced with GTP, leading to release of GEFs from the complex and activation of the GTPase (1,2). Many GEF proteins have been identified as oncogenes and are involved in human diseases such as cancer. Interestingly, the expression of GEF protein is tissue- or cell-type specific, providing a therapeutic potential for cancer treatment (2, 3).

Recently developed fluorescence analogs of guanine nucleotides have greatly improved the technical ability to define the real-time exchange reaction of GEFs, including kinetic and thermodynamic properties, thereby eliminating the need for traditional radioactive labeling methods (4, 5). This fluorescence-based assay takes advantage of the spectroscopic difference between bound and unbound fluorescent analogs to guanine nucleotides and resulting in the ability to monitor nucleotide exchange of small GTPases (4, 5). Once bound to GTPases, the emission intensity of the fluorophore increases dramatically. Therefore, the enhancement of fluorescent intensity in the presence of small GTPases and GEFs will reflect the respective GEF activities of known or unknown proteins.

Cytoskeleton Inc. has developed a N-MAR-GTP fluorophore-based Rho-GEF assay suitable for both 96-well and 384-well formats (6). This assay can be applied to multiple research purposes such as characterizing the GEFs and identifying GEF inhibitors in a high-throughput screen format. This kit contains human Cdc42, Rac1 and RhoA proteins and the GEF domain of Dbs as a positive control GEF for Cdc42 (Fig. 1) and RhoA. Dbs shows extremely low GEF activity for Rac1 (see Fig.2 and Ref. 4). Interestingly, it was reported that human Dbs can activate Rac1 in a FRET-based assay (7).

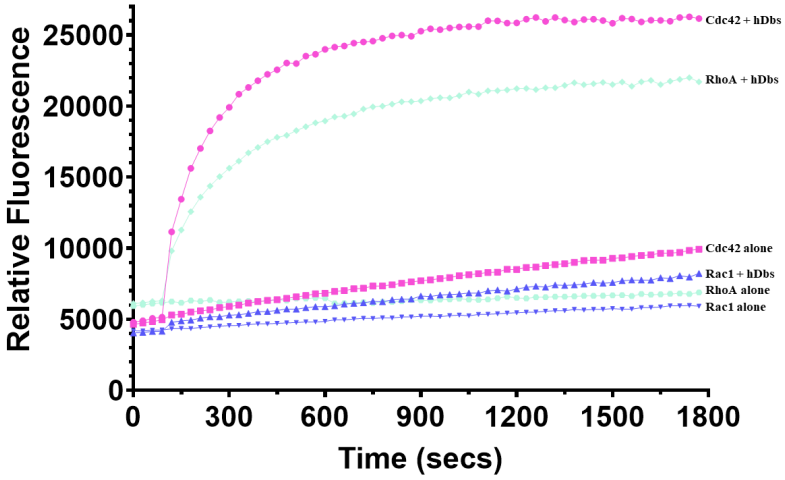

Figure 1. Cdc42, RhoA, and Rac1 exchange assay

Method: The small GTPases Cdc42 (Cat# CD01), RhoA (Cat# RH01), Rac1 (Cat# RC01), and the human Dbs protein (Cat# GE01) were expressed as His-tagged proteins in E. coli and purified on a nickel affinity column. The reactions were conducted in a 96-well black flat bottom half area plate (Corning Cat# 3686) format (100 µl *reaction volumes). Each reaction contains 1.7 µM GTPases, 20 mM Tris pH 7.5, 50 mM NaCl, 10 mM* $MgCl_2$*, and 0.75 µM N-MAR-GTP with or without the presence of 0.5 µM human Dbs (DH/PH) protein. Reactions were measured in a Tecan Spectrofluor plus fluorimeter (*λ *ex= 485 nm,* λ *em= 535 nm). Readings were taken at 20°C every 30 seconds for a total reaction time of 30 minutes. The data shown are the averages of three experiments.*

II: Important Technical Notes

Notes on Updated Manual Version

1) In Version 2.5, the Exchange Buffer (2x) when reconstituted would produce a solution of 40 mM Tris pH 7.5, 100 mM NaCl, 20 mM MgCl2, and 1.5 µM mant-GTP.

2) In Version 4.0, the Exchange Buffer (2x) has been modified to be 40 mM Tris pH 7.5, 100 mM NaCl, 20 mM MgCl2, and 1.5 µM N-MAR-GTP when reconstituted. The N-MAR-GTP results in a higher signal to noise ratio versus mant-GTP and improves the sensitivity of the kit.

The following technical notes should be carefully read prior to beginning the assay:

Exchange assay reagents

1) This kit contains sufficient purified GTPases and N-MAR-GTP to carry out approximately 20 reactions (100 µl volume for 96-well plate) for each GTPase. This corresponds to 60 GEF assays for all three GTPases (Cdc42, RhoA, Rac1) of 100 µl volume using a black flat-bottom 96-well half area plate (Corning plate Cat# 3686). Up to 130 reactions per GTPase can be achieved if a 384-well black round bottom plate (Corning Cat# 3676) is used. This type of 384-well plate is strongly recommended due to the greater signal/noise ratio. DO NOT USE CLEAR PLATES SINCE THAT WILL GIVE YOU SIGNIFICANT BACKGROUND NOISE.

2) The positive control protein, DH/PH domain of human Dbs (Cat # GE01), in this kit provides sufficient reagent for at least 20 control assays in a half-area 96-well plate format and 130 control assays for a 384-well black round-bottom plate format in this assay. Human Dbs is a promiscuous exchange factor for Cdc42 and RhoA, and a weak exchanger on Rac1 (4, 8).

3) The three best characterized small GTPases RhoA, Rac1 and Cdc42 are included in this kit. If you need to examine more GTPases, a wide selection of small GTPases (Ras, Ran, RhoC and a growing number of GEFs) are available from Cytoskeleton Inc. and can be purchased separately (see **Section VII**).

4) Many of the reagents in this kit require reconstitution and division into convenient experiment-sized aliquots. It is important to carry out the aliquoting step as multiple freeze/thaw cycles of some reagents (for example: exchange buffer and purified protein) may result in the inactivation of the reagents. It is strongly recommended to store the exchange buffer (Cat# EB02) without exposing to light for a long period of time.

Assay optimization

The exchange assay kit has been developed to provide a good general substrate for a broad range of research for characterization and examination of guanine nucleotide exchange factors (GEFs). For example, using this kit as outlined in the introduction (**Section I**) will result in a V_{max} value of 1.4 x 10^{-4} mol N-MAR-GTP loaded per mol Cdc42 per second, which is consistent with published data. **The exchange assay should be performed at 20°C. A higher temperature may cause a higher intrinsic (no GEF) rate therefore influencing signal to noise ratio significantly.** It should be noted, however, that optimization of the exchange assay may be needed for any given GEFs. Please refer to **Appendix I** for troubleshooting.

There are several parameters that may particularly affect GEF protein activity:

1) Temperature. An exchange reaction at 20°C is required. Besides the fact that lower or higher temperature may cause significant change on signal to noise ratio, different GEFs may require a different optimal temperature for their normal *in vitro* exchange activity.

2) Protein concentration. A titration of the GEF of interest should be performed to achieve optimal results.

3) Exchange buffer conditions. Although the condition of reaction buffer in this kit has been optimized, it could be necessary to optimize a particular GEF assay by adjusting the salt concentrations (25-500 mM) and the pH (6.0-8.3) using appropriate buffers such as MES, PIPES and Tris.

4) Control reactions. It is important to include control reactions in the assay, particularly if your GEF of interest is in an impure state. Control reactions are discussed in **Section V**.

Instrumentation

A filter-based fluorimeter should be set at an excitation filter wavelength at 485 +/- 20 nm and emission filter wavelength at 535 +/- 20 nm. The bandwidth of the filter should be no more than 25 nm or you may experience significant background noise and reduced sensitivity of the assay. Non-filter based, monochromatic, fluorometers usually have +/- 2 nm bandwidth so there is no problem with bandwidth when using these machines. The fluorimeter should be at 20°C and set on kinetic mode; it is recommended to take a reading once every 30 seconds for at least 60 cycles (30 minutes total). There is no need to elect a blank well, as the reaction without GEFs will serve as a background control.

The majority of the work in the design of this assay was developed on the Tecan GmbH machine called SpectroFluor Plus. This instrument is a filter-based fluorimeter that can detect pmoles of fluorescein. A similar fluorimeter or a SpectraMax ID5 spectrometer are recommended to use for this assay. The parameters of a protocol file for the Tecan instrument is given on the next page:

Uses and applications for this kit:

Measurement type:	Character	Contents
Measurement type:	Kinetic	60 cycles of 1 reading per 30 seconds
Fluorescence wavelengths: *Note: Wavelengths are provided for assays run on monochromatic fluorimeters.*	Filter-based Ex. Em. Monochromatic Ex. Em.	 485 nm ± 20 nm 535 nm ± 20 nm 485 nm 515 nm
Gain:		80 on a scale of 0-120, where 120 is the highest
Reads per well:	Flashes	3
Fluorescence reading from:	Top	
Integration:		0-40 µs
Shaking:	Med, orbital	5 seconds (first read only)
Plate-type:	Greiner	GRE384fb or GRE96fb (flat, black). Standard template on TECAN.
Vmax:	AFU/ second	8 readings

1. Determination of the activity of unknown GEFs.
2. Biochemical characterization of small GTPases and their associated GEFs.
3. Examination of the regulation of GEF activity by different cofactors or protein domains.
4. Screening mutant proteins of either GEFs or GTPases for activity and substrate specificity.
5. Identification of GEF inhibitors in a HTS (high throughput screen) format.

III: Kit Contents

KIT COMPONENT	DESCRIPTION
Exchange Buffer (2x) (Part# EB02)	One bottle, lyophilized. When reconstituted: 40 mM Tris pH 7.5, 100 mM NaCl, 20 mM $MgCl_2$, 1.5 µM N-MAR-GTP.
Cdc42-His protein (Cat# CD01)	One tube, lyophilized. Contains 100 µg of purified His tagged Cdc42 protein.
RhoA-His protein (Cat# RH01)	One tube, lyophilized. Contains 100 µg of purified His tagged RhoA protein
Rac1-His protein (Cat# RC01)	One tube, lyophilized. Contains 100 µg of purified His tagged Rac1 protein.
hDbs-His protein (Cat# GE01)	One tube, lyophilized. Contains 50 µg of purified His tagged human Dbs protein (DH/PH domain).
384-well plate	One 384-well black half area round bottom plate (Corning Cat# 3676)
96-well plate	One 96-well black half area flat bottom plate (Corning Cat# 3686)

Please inquire for significant discounts on large quantities of any reagents in this kit.

IV: Things to do Prior to Beginning the Assay

Reaction mixture preparation:

Prior to beginning the assay you will need to reconstitute several components as follows:

Kit Component	Reconstitution	Storage Conditions
Exchange Buffer (2x)	1) Dissolve the powder in 5 ml of distilled water. 2) Aliquot into 10 x 0.5 ml sizes.	Store at -70°C. Stable for six months under these conditions.
Cdc42-His protein	1) Briefly centrifuge the tube to make sure all the white protein powder is at the bottom of the tube. 2) Check that you can see the white powder pellet. 3) Reconstitute in 20 µl of distilled water to give a 200 µM (5 mg/ml) solution. 4) Aliquot into 5 x 3.5 µl sizes. 5) Snap freeze in liquid nitrogen.	Same as above.
RhoA-His protein	Same operation as Cdc42-His protein.	Same as above.
Rac1-His protein	Same operation as Cdc42-His protein.	Same as above.
hDbs-His protein	1) Briefly centrifuge the tube to make sure all the white protein powder is at the bottom of the tube. 2) Check that you can see the white powder pellet. 3) Reconstitute in 25 µl of distilled water to give a 50 µM (2 mg/ml) solution 4) Aliquot into 5 x 4.5 µl sizes. Snap freeze in liquid nitrogen.	Same as above.

V: Assay Protocol

The following protocols are for either a 96-well plate format or 384-well plate format (Corning Cat# 3686 and 3676, respectively). We highly recommend the 384-well plate we provided in this kit. You can adjust the volume by ratio if you are using different volume plates. The exchange reaction is started with all of the reaction components, minus GEFs. GEF is added after 5-10 readings to examine its exchange activity.

Reaction protocol for 96-well plate

1) Set up and test the plate reader and kinetic parameters, and prepare protein or other samples prior to start.

2) Thaw an aliquot of 2x Exchange Buffer by placing in a room temperature water bath for 1 minute. Keep at ROOM TEMPERATURE and protect from light (foil wrap works well for this).

3) Thaw one 3.5 µl aliquot of respective GTPase stock (200 µM) depending which GTPase you want to test (Please refer to **Section VII** for more GTPase choices), by placing in a room temperature water bath for 1 minute. Dilute to 42 µM by addition of 13 µl of Nanopure water and place on ice.

4) Thaw one 4.5 µl aliquot of positive control protein human Dbs or your own GEF by placing them in a room temperature water bath for 1 minute. Dilute to 5 µM by addition of 41 µl Nanopure water. Place on ice.

PLEASE ADJUST THE ALIQUOTED VOLUME BASED ON HOW MANY REACTIONS YOU NEED AND WHICH KIND OF PLATE YOU ARE GOING TO USE. The recommended working concentration of GEFs is 0.2 – 2 µM (consider the percent purity of your GEF protein in this calculation). NOTE: We use 0.5 µM GEF in the standard hDbs assay (see **Figs. 1 – 3**). You may want to titrate the concentration of GEF in your particular experimental set up.

5) Add the following components together at ROOM TEMPERATURE and mix well by pipetting or gentle vortex:

Exchange reaction mix:	**One 96-well reaction:**
2x Exchange Reaction Buffer (Part# EB02)	50 µl
Respective GTPase (42 µM) (Cat# CD01, RH01, or RC01)	4 µl
Nanopure water	36 µl

PLEASE ADJUST YOUR VOLUME BASED ON THE PLATE YOU ARE USING. THE RECOMMENDED VOLUMES HERE ARE BASED UPON TOTAL VOLUME OF 100 µl (96-WELL HALF AREA PLATE, CORNING CAT# 3686)

6. The reaction mix is now ready for the fluorescence reading (See Section II for recommended instrument settings). Aliquot to the assigned well and place the plate in the fluorimeter.

WE STRONGLY RECOMMEND THE OPERATION TEMPERATURE FOR THE FLUORIMETER SHOULD BE 18-22°C. A HIGHER TEMPERATURE MAY CAUSE A HIGHER INTRINSIC RATE AND THUS INFLUENCE THE SIGNAL/NOISE RATIO SIGNIFICANTLY.

7) After 5 readings (150 seconds), pipette 10 µl of either your GEF, hDbs protein (5 µM) or nanopure water (intrinsic control) in respective wells and immediately pipette up and down twice and start reading.

IT IS RECOMMENDED TO ADD GEF PROTEINS (OR WATER) USING A MULTICHANNEL PIPET TO ENSURE ALL REACTIONS BEGIN SIMULTANEOUSLY. IT IS IMPORTANT TO KEEP THIS PROCESS AS SHORT AS YOU CAN TO GET A SMOOTH CURVE. KEEP READING INDER THE SAME CONDITIONS.

8) Save the readings after the kinetic protocols are finished. The exchange rate can be calculated by reducing the data to Vmax with the software that accompanies the plate reader. The exchange curve can be achieved by exporting raw data to Microsoft Excel. Examples using positive control hDbs are shown in **Figure 2**. To calculate the specific activity please read **Appendix II.**

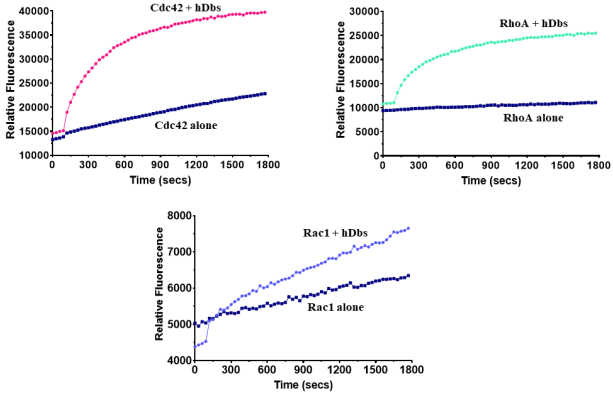

Figure 2. Dbs exchange activity for Cdc42, RhoA and Rac1 in 96-well half area plate format. The data shown are the averages of three experiments.

Reaction protocol for 384-well plates (Corning Cat# 3676) - Highly recommended, especially for high-throughput screening

1) Set up and test the plate reader and kinetic parameters, and prepare protein samples or compounds prior to start.
2) Thaw the relative amount of respective GTPase and GEF, drug solution (for high throughput screen of GEF inhibitors only) by placing in a room temperature water bath for 1 minute. Place on ice.
3) Thaw a 2x Exchange Buffer aliquot by placing in a room temperature water bath and leave at room temperature, protected from light.
4) Thaw one 3.5 µl aliquot of respective GTPase stock (200 µM) depending which GTPase you want to test (Please refer to **Section VII** for more GTPase choices), by placing in a room temperature water bath for 1 minute. Dilute to 14 µM by addition of 49 µl of Nanopure water and place on ice.
5) Thaw one 4.5 µl aliquot of positive control protein human Dbs or your own GEF by placing them in a room temperature water bath for 1 minute. Dilute to 5 µM by addition of 85 µl Nanopure water. Place on ice.
6) Add the following components together at ROOM TEMPERATURE and mix well by pipetting or gentle vortex:

Exchange reaction mix:	**One 384-well reaction:**
2x Exchange Reaction Buffer (Part# EB02)	7.5 µl
Respective GTPase (15 µM) (Cat# CD01, RH01, or RC01)	2 µl
Nanopure water	2.5 µl

PLEASE ADJUST YOUR VOLUME BASED ON THE PLATE YOU ARE USING. The recommended volume here is based upon total volume of 15 µl (384-well black round bottom half area plate, corning Cat# 3676). The recommended working concentration of GEFs is 0.2 – 1 µM (Consider the percent purity of your GEF protein in this calculation). NOTE: we use 0.5 µM GEF in the standard Dbs assay (see Figs. 1 – 3), you may want to titrate the concentration of GEF in your experimental set up.

For HTS only: THE FINAL CONCENTRATION OF DRUG SOLUTION WE RECOMMEND IS 10 µM – 0.5 mM. We recommend you titrate your drug solution for optimal results. Generally a concentration at 30 µM – 50 µM is good for initial screening.

7) The reaction mix is now ready for the fluorescence reading (see recommended Ex/ Em table Section II). Aliquot to the assigned wells and place the 384-well round bottom black plate in the fluorimeter.

WE STRONGLY RECOMMEND THE OPERATION TEMPERATURE FOR THE FLUORIMETER SHOULD BE AROUND 20°C. A HIGHER TEMPERATURE MAY CAUSE HIGHER INTRINSIC RATE AND THUS INFLUENCE THE SIGNAL/NOISE RATIO SIGNIFICANTLY.

8) After 5 readings (150 seconds), add 3 µl of the 2.5 µM GEF (or hDbs) protein or dH_2O to respective wells and immediately pipette up and down twice and resume reading.

IT IS RECOMMENDED TO ADD GEF PROTEINS (OR WATER) USING A MULTICHANNEL PIPET TO ENSURE ALL REACTIONS BEGIN SIMULTANEOUSLY. IT IS IMPORTANT TO KEEP THIS PROCESS AS SHORT AS YOU CAN TO GET A SMOOTH CURVE. KEEP READING INDER THE SAME CONDITIONS.

9) Save the readings after the kinetic protocols are finished. The exchange rate can be calculated by reducing the data to Vmax with the software that accompanies the plate reader. The exchange curve can be achieved by exporting raw data to Microsoft Excel. Examples using positive control Dbs are shown in **Figure 3.** To calculate the specific activity please read **Appendix II**.

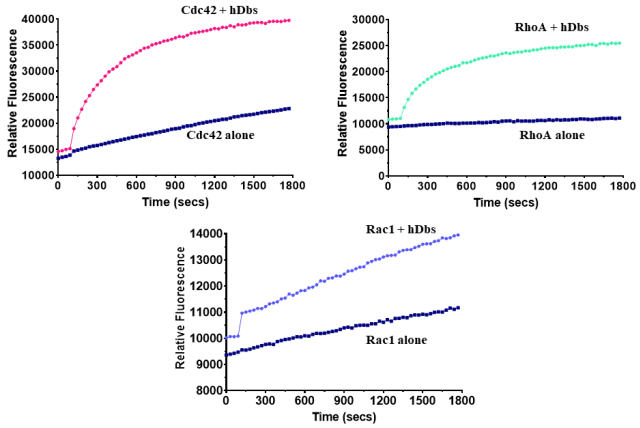

Figure 3. Dbs exchange activity for Cdc42, RhoA and Rac1 in 384-well half area plate format. The data shown are the averages of three experiments.

VI: References

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Citations for BK100

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VII: Related Products

ITEM CAT#	GTPases	Ras subfamily	QUANTITY
CD01	Cdc42 protein (His-tagged)	Rho	1 x 100 µg
RH01	RhoA protein (His-tagged)	Rho	1 x 100 µg
RC01	Rac1 protein (His-tagged)	Rho	1 x 100 µg
RS01	H-Ras protein (His-tagged)	Ras	1 x 100 µg
RS03	K-Ras protein (His-tagged)	Ras	1 x 100 µg
RS04-RS14	K-Ras mutants G12C, G12D, G12V, G12D+I36N, G12D+D38A, G13D, G13S, Q61P, K128A, and R135A proteins (His-tagged).	Ras	1 x 100 µg
RC03	RhoC protein (His-tagged)	Rho	1 x 100 µg
CS-GE01-A CS-GE01-C	Human Dbs protein (His-tagged)	Rho GEF family	1 x 50 µg 3 x 50 µg
CS-GE02	SOS1 GEF protein (Exd exchange domain, aa564-1049, His-tagged)	Ras	1 x 100 µg
CS-GE03	RasGRF1 GEF protein (Cdc25 exchange domain, aa 1038-1270, MBP-tagged)	Ras	1 x 100 µg
CS-GE04	Tiam1 GEF protein (DHPH exchange domain, aa 1040-1406 MBP-tagged)	Rho	1 x 100 µg
CS-GE05	VAV1 GEF protein (DHPHC1 exchange domain, Y174D mutant, aa 168-522, His-tagged)	Rho	1 x 100 µg
CS-GE06	VAV2 GEF protein (DH exchange domain, aa 189-374, His-tagged)	Rho	1 x 100 µg
CS-GE07	ARNO GEF protein (Sec7 exchange domain, aa 31-267, His-tagged)	Arf	1 x 100 µg
CS-GE08	SOS12 GEF protein (Exd exchange domain, aa563-1051, His-tagged)	Ras	1 x 100 µg
BK008	Ras activation assay biochem kit	Ras	25 assays
BK034	Cdc42 activation assay biochem kit	Rho	25 assays
BK035	Rac1 activation assay biochem kit	Rho	25 assays
BK036	Rho activation assay biochem kit	Rho	25 assays
BK101	Ras GEF exchange assay	Ras	25 assays

Note: Many more GTPase are available online at https://www.cytoskeleton.com/small-g-proteins/proteins.

Appendix I: Troubleshooting

Observation	Possible cause	Remedy
1. No increase in fluorescence after adding positive control Dbs.	1. Sensitivity of fluorescence spectrophotometer set too low . 2. Incorrect labeling of tubes. 3. Inactive proteins.	1) Increase sensitivity by: increasing emission gain or increase intensity of excitation. 2) Repeat the experiment. 3) Follow correct storage
2a. During the assay, increase in fluorescence is too slow for tested GEF protein.	1. GEF concentration is too low or GEF is a weak exchanger for this GTPase. 2. Excitation light is too intense. 3. Purity of GEF protein is too low. 4. GTPase concentration is too low.	1) Increase GEF concentration or titrate the GEF concentration. 2) Reduce excitation light intensity. 3) Increase GEF purity. 4) Increase GTPase concentration.
2b. During the assay, increase in fluorescence is too slow for positive control Dbs.	1. Excitation light is too intense. 2. GTPase concentration is	1) Reduce light intensity. 2) Increase GTPase concentration.
3. During the assay, increase in fluorescence is too quick.	1. GEF concentration is too high. 2. GTPase concentration is too high. 3. GEF is a strong exchanger for specific GTPase.	1) Decrease GEF concentration. 2) Decrease GTPase concentration.
4. During the assay increase in fluorescence is not reproducible.	1. Inconsistent preparation of reaction mixture. 2. GEF protein is not stable due to poor purity.	1) More consistent technique, increase pipetting accuracy, or test machine for signal stability using buffer alone. 2) Increase the purity of the protein by optimizing the purifying process, e.g. reducing the proteases.

Appendix I: Troubleshooting

Observation	Possible cause	Remedy
5. During GEF assay increase in fluorescence is low.	1. Concentration of GEF too low 2. The GEF is a weak exchanger for a specific GTPase.	1) Increase GEF concentration. 2) Perform the experiment together with positive control GEF.
6. Buffer components of the reaction interfere with the activity of the test protein or compound.	1. Tris-HCl 2. pH 3. $MgCl_2$ 4. NaCl	1) Tris-HCl: Make new GEF Buffer with a different "GOOD" Buffer. 2) pH: Generally GEF can function at pH6.0-8.5. 3) $MgCl_2$: Lower the concentration to 5 mM. 4) NaCl: Adjust the concentration to 20 mM.
7. The intrinsic exchange rate is too high.	1. The reaction temperature is too high.	1) Cool down the instrument to 20°C.
8. Test GEF protein has no exchange activity.	1. Test GEF does not exchange the specific GTPase. 2. The optimized condition is not good for testing this GEF protein.	1) Try different GTPases. 2) Titrate pH etc. for optimal results.

Appendix II: Specific Activity Calculation

Two steps to calculate specific exchange rate:

1. [Vmax (AFU/sec)] / [Basal N-MAR-GTP AFU* x N**] = A (µM/sec)
2. Exchange rate = A / 0.75*** (µmol N-MAR-GTP/µmol GTPase/sec)

* Basal N-MAR-GTP level is the start point level of fluorescence units of 0.75 µM N-MAR-GTP without GEF under our condition.

** N = quantum yield (our unpublished observations):

For Cdc42, N = 5

For RhoA, N = 3.3

For Rac1, N = 1.4

*** This number is based upon fully N-MAR-GTP loaded GTPases.

Example:

This example calculation uses data derived from Fig 1 in this manual (Page 3):

1. [Vmax (AFU/sec)] / [Basal N-MAR-GTP AFU* x N**] = 2.6 (AFU/sec) / 5000 AFU x 5
   $= 1.04 \times 10^{-4}$ (µM/sec)

2. Therefore, Exchange rate $= 1.04 \times 10^{-4}$ (µM/sec) / 0.75 µM
   Volumes cancel out,
   $= 1.4 \times 10^{-4}$ (µmol N-MAR-GTP/µmol Cdc42/sec)

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