Technologies Theme Action Plan

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Vision of the Theme Action Plan.
Using and developing technology is an essential component of NERC research and a vibrant, dynamic and innovative technology skills base is central to enabling world-class environmental science. Providing opportunities to develop and share new technological approaches across all of the NERC science disciplines is the vision of the theme.

What is the Scope?
A decision to develop a technology strategy was approved in 2005 and Council subsequently identified Technologies as one of its seven themes for the 2007-2012 strategy. The theme scope is for technology development of instruments, platforms, sensors and techniques provided or used for environmental science. This also includes information and communication technology, high performance computing and e-science technologies, as well as numerical techniques. In some areas direct adoption of commercially available technology is possible (for example by direct procurement) and mechanisms for provision lie outside of the theme. However, there are challenging areas where NERC must drive forward, through targeted research programmes, the development of bespoke technologies and the theme will provide leadership in these areas. This theme aims to engage scientists, technologists, computer specialists and engineers working both within the NERC community and outside, identifying that in many cases it will only be through developing new partnerships that the most challenging innovations in technology will be enabled.

High Priority Theme Challenges
A strategy development panel in conjunction with community input prepared a theme report which was updated following discussion in SISB. The theme report was used subsequently to generate a Technology Management Plan (TMP), which helps guide this Theme Action Plan (TAP). The format of the TMP differs from the other six theme reports. Rather than presenting 'grand challenges' or 'science questions', it identifies broad community-wide technology topic areas, the development of which are considered central to delivering NERC strategic goals. There are cross-community high-priority challenges of supporting blue sky activities and the retention of the skills-base for undertaking technologies research. The TMP and technologies theme report also identifies high-priority challenges relating to the development of new technologies in four strategic areas:

- remote sensing and earth observation,
- intelligent field sensors and networks of sensors,
- novel laboratory instrumentation,
- informatics, models and data.

The technologies theme envisages supporting and encouraging new research activities in all of these areas and will aim to maintain a balance of technologies that may be used for applied science now and those that may seed future technology.

Actions to be implemented this year.
Prioritisation with respect to timing has been necessary in developing actions for the 2008 TAP. The focus in this TAP is on supporting technologies across the entire community, as a key means to address the challenges of developing and retaining the technologies skills and knowledge base. The actions in these areas relate to reinforcement of technologies research eligibility for responsive mode funding, the monitoring and benchmarking of existing activity and the development of a new technologies Proof of Concept support mechanism. Additionally new investment will be made in community-wide activities to network technologists and technology between science disciplines

and as a principle forum for the development of future TAP actions. The four actions will make a key contribution to the long-term stability of the research base by providing essential continuity of opportunity.

Consultation on the actions proposed here has been undertaken using focused expert groups and through discussions with representatives from RCCs and certain HEIs. A number of new activities within individual challenge areas are to be undertaken where compelling reasons for prioritising their timing exists. These actions are elaborated further in individual descriptions. Certain other actions in this TAP are described in some detail at an outline stage for the purposes of discussion, refinement or subject to scoping study. These will be detailed for recommendation in later TAPs. A brief summary of Technologies actions described in this TAP are:

- A scoping study into opportunities for future activity in instrumentation for next-generation observing platforms. Also included in this action description are details of example activities, size and science topic areas, commitment to which would be in a future TAP revision and dependant on the scoping study outcomes.
- A consortium building activity as a precursor to creating a number of distributed networks of environmental sensors pilot projects, enabled through research-agency-industry partnerships.
- A targeted activity to stimulate the development of novel laboratory instrumentation for the determination of fundamental parameters – to be delivered in combination with the new Proof of Concept action.
- A future joint activity led by Climate Systems on the scoping of technologies needed for next-generation climate models. Based on the outcomes of further consultation on this action a commitment to a commissioning would be presented in future TAP revisions.
- A potential future targeted activity with the EPHH theme and with EPSRC for the development of a new generation of environmental field sensors.

Development of future actions

In future revisions of the TAP it is envisaged that all challenge areas will be targeted for certain direct actions and the proposed Technology Clusters will become a key means for the community to guide these actions. When new technology needed to help deliver science in the other six NERC themes are identified, the Technology theme will aim to respond to these challenges.

Details of Actions.

Action 1. Expanding the coverage of responsive mode

Rationale and Objectives

The TMP highlights that the ability to undertake 'blue sky' research into new technologies for environmental science should be served by the Responsive Mode (RM) funding mechanism. Much research in this area however is perceived to fall between Research Councils, most often with EPSRC, and this has often led to the activity being viewed as peripheral. Historical statistics on RM indicate that Technologies receives the smallest proportion of funding through this mechanism when compared with the other six themes. For NERC to develop and exploit evolving state-of-the-art technologies will by its very nature require the bottom-up support mechanism to function effectively. Without the correct functioning of blue-sky support mechanisms, there is no sustainability of research opportunity and by extension the skills base. The objective of this action is to facilitate a shift in community and College *perception,* and reinforce that technologies-led proposals are included within existing RM coverage.

Implementation mechanisms

NERC will undertake active dissemination of the eligibility of NERC technology-led proposals to the RM within one year. The action will require promotion internally within NERC, its peer review College and in the wider community. It is appreciated that the cultural shifts in opinion required are very large but this action is seen as an essential first step. The specific mechanisms that could be used for this are wide ranging and will be developed internally by NERC.

A future outcome of this action may be that clearly articulated and more technologically focused RM proposals will increase visibility of NERC activity in this area, to not only other research Councils, but also industry and other potential funding agencies. This may increase opportunity for co-funding support of such projects with external partners.

Action 2. Responsive Mode – monitoring and benchmarking of technologies.
Rationale and Objectives
Certain difficulties in monitoring and benchmarking technologies-led proposals submitted to RM will be addressed through a separate action. At present it is potentially difficult for non-experts (in a particular technology) to make informed judgments of true technological innovation or the innovation in the translation of a technology to a new field. This is vital, however, in a newly-developed theme to ensure that only excellent science is supported. Additional expertise beyond the College will be sought, with a specific remit to a) provide benchmarking of 'NERC' technology when placed in a wider context, b) identify cross Research Council or industrial relevance where appropriate, and c) provide horizon scanning input to the Theme Leader and NERC. Uniquely to this theme it is considered that the outcomes from RM should be fed back as input to guide future evolution of the TAP. Categorisation of proposals at the submission stage (e.g. through Je-S) as technologies-led will be a mechanism to monitor current expertise and activity levels.

Implementation mechanisms.
The TAP recommends that for a time limited period (e.g. 2 years) a panel within RM to consider all proposals identified (by applicants) as technologies-led. Such a panel would consist of College members and a small number of technologists (4-6 members) without vested interest Depending on demand an alternative may be for a NERC technology expert group to be convened (potentially in a virtual manner) to provide expert comment/advice on technology proposals to be considered by moderating panels. In order to allow for a period of consistent benchmarking, it is recommended that the small number of technology experts should remain on the College for an extended period. Beyond the proposed monitoring period of two years NERC would, if appropriate, revert to back to current procedures.

Action 3: Technologies Proof of Concept
Rationale and Objectives
The theme report and TMP highlight that the technologies theme should address generic support issues for technologies spanning a wide range of Technology Readiness Levels (TRL[2]). The TMP identifies a gap in support mechanisms for the lowest TRLs and in particular for Proof of Concept (PoC). This action will create new opportunities for the support of technologies research at this highly developmental stage. The key rationale for enhancing such activity is that it fosters a dynamic and vibrant research base within both HEIs and RCCs where high risk - high reward technologies can be developed. It allows researchers to directly address issues of risk and cost-effectiveness in technologies development, and provides NERC with a mechanism to ensure that major investments are only made after demonstration of initial feasibility or passing of design /

[2] TRL is a nine-point scale used widely within technologies industries and the defence sector for describing the evolution of a particular technology into usage. TRL1 refers to the most speculative technology where only basic supporting data or theoretical calculations exist to TRL9 which is effectively fully mission proven and likely to available via direct procurement. See NASA definition at http://esto.nasa.gov/files/TRL_definitions.pdf

theoretical milestones. Although figures can vary widely, typically 10% of total cost in a new technology development project might be associated with the PoC stage.

There are a number of important additional benefits associated with a PoC support mechanism:

- Provide an accessible route to engage non-NERC communities with pressing environmental technology problems and bring new specialist expertise into the field.
- Be an internationally competitive innovator for not only generating NERC follow-on research but in seeding ideas and activities to be carried forward by other RCs, the Technology Strategy Board (TSB), by industry and other funders.
- Provide a mechanism to support technologies research across the entire community and be a partial contributor to the maintenance and enhancement of overall U.K. capability in the theme area both in RCCs and HEIs.
- Create a delivery mechanism for targeted investments in technology development as needed to meet NERC strategic needs.

There exist a range of potential follow-on support routes for successful PoC studies, many of which are external to NERC. This action is considered of particular relevance in stimulating commercial interactions, where a demonstration of technical feasibility gives substantial leverage with potential industrial and manufacturing partners. There remains however the need for NERC to take retain sufficient flexibility in resource that 'star performing' PoC projects, which do not have potential for external exploitation and where the science need is compelling, to be carried forward into operational technology. The objective of such an action would be to avoid the loss of key skills, expertise and project momentum between the end of any PoC work and potential start-up following a resubmission/review/award.

Implementation mechanisms.
NERC will establish an annual Proof of Concept activity for research into new and innovative technologies for environmental science. Such a scheme will sit at the heart of the NERC Technologies theme and operate as an enabling mechanism for delivering new technologies both in the four strategically identified areas and those outside. The scheme will support activity at TRL1-TRL4/5 and be broad ranging in the activities considered suitable; from paper studies to laboratory experiments. Research at higher TRL levels would be considered as being closer to procurement and more appropriate for support through other mechanisms.

The PoC activity will operate on an annual basis over a period of five years, and £3.4M is now committed to this activity. A key benefit of this action will be its positive contribution to longer term sustainability and retention of the community by providing stability of research opportunity. As such the management overhead of the action is a relatively small cost of meeting and addressing this vitally important longer term challenge.

Action 4. Technology Clusters
Rationale and Objectives
The TMP considered that communication between researchers working in common technology fields is central to maximizing NERC impact and in enabling new and innovative technological solutions. Whilst opportunities for discussion, horizon scanning and dissemination exist extensively within any applied science area, e.g. marine, atmospheric etc, opportunities across technology fields are rarer. Without an established mechanism for interactions there is risk that new developments do not hop disciplines, best practice is not shared effectively, or at worst that effort is wasted through duplication.

This action makes a commitment to support community activities centred on individual technology topics. The action will enable the formation of technology Clusters which will be cross-application area in scope and provide communities with a forum for technology sharing, training and as a means to network between NERC communities and externally with other researchers and industry. The action aims to create a supportive and vibrant environment for technologies research, to support existing communities and to highlight opportunities in the field in both the short and long term to new entrants.

The individual Clusters will be charged with holding regular technology events, supporting targeted training and education, coordinating and funding academic and technological staff exchange and providing seed corn support for new initiatives. The Clusters, through their steering groups, will provide NERC and the TL with annual horizon scanning opinions in specific technology areas and this will be a vital input to future TAP revisions and in directing new activity. Cluster meetings and expert groups will be a central means for consulting on new technologies actions within specific challenge areas and be a route to assemble effective consortia to meet future directed challenges, e.g. implementation of pilot networks, action 6. The Clusters will also provide an active route to showcase new technology to other communities and TLs and to stimulate interactions and pull-through of technology into use.

Implementation mechanisms.
NERC will support the formation of Clusters initially in the four strategic technologies areas but with potential for future additions and change. The Clusters will support community meetings and small-scale research activities, networking opportunities and training events. The Clusters will be expected to be fully-engaged with, and contribute to, NERC KE activities.

Action 5. Remote sensing technology for next-generation platforms – Scoping study.
Rationale and Objectives
The UK is a major user of remote sensing and earth observation data but has a current lower level of activity in new technology development. NERC has supported orbital projects such as HiRDLS and GERB, but placed internationally it is a relatively small player in space-based technology research. Within the current NERC portfolio, and internationally, there exist gaps in the ability to bridge between ground and space platforms and between regional and global measurement scale.

The action is for some targeted research activity, to evolve over time, in an area where it is believed the U.K. can play a lead role in both observations and the underpinning technologies. The objective is to enable the timely development of new instrumentation technologies targeted for, and ultimately mission proven on, emerging *next-generation* unmanned platforms[3]. There are many areas that have potential to be revolutionised by more frequent and higher resolution regional scale observations – from Polar regions[4], to remote oceans and terrestrial locations. Observations from such platforms have the opportunity to provide high-resolution constraints in a number of science topics, and a number of community examples are given below. Next-generation observation systems developed here should fit fully within 'systems of systems' approach and be compatible with, and provide a UK contribution to, international activities such as GEO, GEOSS and GMES. A key driver for the development specifically of new suborbital remote sensing technologies is that they may yield essential data in support of other themes within relatively short

[3] Next-generation of platforms include long duration UAVs (Unmanned Autonomous Vehicles) - both aerial and underwater, zeppelins and high altitude platforms (HAPs). Note: Internationally, for example within NASA, NOAA, UAVs are seen as highly powerful future aerial observing platforms, and direct procurement of platform infrastructure is becoming possible. The view of this TAP is that the international science lead is likely to fall to those with the most advanced portfolio of instrument technologies that can take advantage of commercially available UAV platforms as they move into the environmental science domain.
[4] The action directly addresses the aspirations of improved observations in inhospitable and remote environments, recommendations from para 67, NERC Polar Science Working Group strategy document.

timescales, compared to space borne EO. A further and important benefit is that proven suborbital demonstrations of technology have potential to be highly influential on the international stage in the commissioning of mission payloads both within ESA or possible future bilaterals.

Four example technique/science areas for potential development for aerial platforms through such an action if carried to full delivery beyond the scoping study:

- High accuracy geostationary surface measurement or mobile surveying of natural (e.g. volcanic) or anthropogenic (e.g. Carbon capture facilities) CO_2 releases using bespoke hyper spectral sensors mounted on autonomous UAVs.
- High temporal and spatial resolution of ground level and tropospheric pollution (e.g. NO_2, PM, HCHO) using compact UV/VIS/SWIR spectrometers located on high altitude stationary HAP platforms.
- High-resolution ice-sounding surveys (accumulation history, internal layers, basal boundary conditions and depth) using compact P band radars from UAVs flying in hostile and remote environments beyond the range of current manned facilities.
- Determination of vegetation / biomass structure and carbon stocks using canopy LIDAR, thermal and hyperspectral devices either from high altitude platforms for long term monitoring or surveying UAVs in remote environments.

Implementation mechanisms.
NERC will support the development of novel remote sensing technology that can utilise current unmanned autonomous platforms (both aerial and submersible) to deliver high quality science in the near to medium term, but with design focus on future UAV platforms built-in. There is a strong timeliness driver to begin this activity now since development timescales in this technology area can be long. A scoping and consultation study (e.g. competitive tender) utilising independent expertise will be undertaken. The scoping study will cover both instrumentation technologies that may be developed through the theme, science activities that they would support, their linkage to the other six strategy areas (and TAPs) and UAV infrastructure opportunities as advice for future partnership and NC needs. The scoping study will provide a clear development plan that can be incorporated into future TAPs. The recent findings of horizon scanning events such as those held by CEOI will also be considered by this study. Given a recognised UK space technology weakness in the technology demonstration area potential collaborations will also be pursued.

The outcomes from the scoping and consultation will inform the development of the TAP and guide any commissioning of activity in the medium term. Looking forward however, each technology project may be of the order £0.5M – £1M, and 3-5 projects could be developed to generate platform demand and critical mass of expertise. Implementation mechanisms must be sufficiently flexible as to accommodate a range of project development timescales from 3 years to perhaps as long as 6-7 years.

Links and dependencies
There is a very substantial portfolio of remote sensing and earth observation activities which fall under the NERC umbrella, *via* virtually all of its RCCs, within projects funded in HEIs, through S&F such as ARSF and FAAM, and indirectly *via* the UK ESA subscription. Potential interest in participation in such activities, in particular for polar UAV remote sensing has been expressed by DEFRA, FCO and MOD and will be explored further and as a NERC contribution to the cross Council Global Security Initiative, although this does not form an explicit dependency of the action.

Action 6: Networks of sensors – pilot high-resolution networks.

Rationale and Objectives

Distributed high-density networks of sensors are identified in a number of the strategy themes as offering potential paradigm shifts in the way that we observe and study the environment. Substantial sensors research in the UK and internationally is focussed at low TRL levels and in practice few live sensor networks for environmental research actually exist; there has been historically a disconnection between basic development of devices in the lab and their pull through into a research environment.

Several theme reports highlight specific sensor opportunities and the science areas where they have potential to make major impacts e.g. EPHH – for airborne pollutants and diseases, Hazards - for surface extreme weather prediction, SUNR – water quality and soil moisture, Biodiversity - biosensors. Despite the many aspirations to widen monitoring and measurement science to higher spatial densities and scales, there has been only limited progress in implementation. Without exemplars or demonstrators, envisaged here through pilot networks tackling real research problems, the true scientific potential of high-density networks of sensors will remain untested.

The specific objective of this action is for the Technologies theme to take the lead in supporting a small number of state-of-the-art, high-density networks of field sensors acting as pilot projects for the observational concept. The focus of the action is on developing pilot projects where it is the *density* and *spatial* resolution of the observational approach that is new, and not necessarily the underlying sensor itself. Such projects require input from many partners and require positive community commitment to large-scale projects. Effectively there is a sensors 'energy barrier' which must be overcome – a requirement for a network of 10 new field devices is uneconomic for industry engagement but one of 100 or 1000 may provide impetus for private sector investment. Similarly engagement with partners who may offer novel sensor platforms (e.g. mobile phones, street lamps, vehicle fleets etc) is likely to be best achieved at first through a commitment to a small number of high profile pilot projects.

The action aims to support pilot projects of ambitious and large enough scope to overcome the new device energy barrier and be internationally leading in the science fields that they will access. The aspiration is for three pilot sensor networks to be commissioned and developed over the 2010-2013 timeframe. Such networks are likely to require substantial resources focused at the implementation level and will have to demonstrate end-to-end integration – that is, collection, calibration, transmission, databasing and assimilation using mature or close-to-market sensors technology. Such an activity will require new collaborations between NERC communities, agencies with operational experience and device manufacturers. Since the objective of this action is to create research networks which will contribute data to other themes, there is urgency to begin this task now.

The choice and types of sensor networks will be driven primarily by the excellence of science that they will enable or unlock, and there are many potential technologies and application areas. Three examples of possible pilot U.K. sensor networks (over a range of time/spatial scales) are given below, all of which have strong theme relevance and play to UK strengths:

- Long time-series high-resolution and accuracy UK-wide GPS / GPRS network to determine geological movement and yielding unique European data for the interpretation of both land shift and sea level change.
- Very high resolution weather networks – using new low cost meteorology sensors with GPS or LIDAR water remote sensing to create highly instrumented tested grids at the 1.5 km scale for real-time improvement of forecasting of extreme weather on the 1-12 hour timescale.

- Instrumented cities for air pollution exposure and prediction – using emerging sensor technologies for O_3 and PM in conjunction with city-wide WiFi communications to generate real-time exposure assessments at the 100 metre scale.

Implementation mechanisms.
The development of consortia capable of the necessary integration of technologies (sensor, communication and informatics) is central to the success of the action. A guide resource for each network may involve an NERC contribution between £0.5-1M.

Whilst the TAP is committed to the *principle* and *scope* of the proposed action, specific financial commitments to individual pilot networks may be requested in future TAPs. This would require a full scientific case to be prepared alongside technical and co-funding specifications from individual consortia – presented either to an expert panel or to SISB by the consortium lead scientist.

Action 7. Novel laboratory instrumentation – measurement of fundamental parameters.[1]
Rationale and Objectives
Laboratory instrumentation forms a \$35B yr^{-1} global market with substantial commercial R&D investment. Many NERC scientists use of state-of-the-art laboratory instrumentation but very few are involved in its development. A generality is that the community procures commercially and then modifies aspects such as sample preparation or data analysis to fit non-standard needs. A vital area where commercial procurement is often not possible however (due to small market and highly specialised requirements), and where there is a U.K. track record in developing new and unique instrumentation (or ensembles and experimental rigs), is for determination of fundamental physical and chemical parameters. Examples include instrumentation for determining rate constants and Arrhenius parameters, absorption cross section and quantum yields, uptake, phase and solution constants, geo-mechanical properties, exchange fluxes and fundamental mechanistic data.

Obtaining new more accurate parameter data is now generally limited by instrumentation and measurement technology; for example in the ability to observe reactive intermediates rather than proxy species in kinetic systems or to observe directly fluxes between environmental compartments. The range of technologies applied to this field is wide-ranging, often utilising the latest technology in high resolution spectroscopy, high repetition lasers and high speed/accuracy mass spectrometry. The integration of such state-of-the-art technologies into simulation or experimental environments (e.g. reactors and chambers, including biological and open-air) is part of this action, as is developing laboratory instrumentation which exploits NERC facilities such as MSF and national resources such as the Diamond Light Source (DLS) synchrotron.

This action aims to stimulate new technological development of novel laboratory approaches for the measurement of environmental parameters, mechanisms and constants. The specific technologies supported through the action will be targeted at environmental processes where improved parameter data would reduce uncertainty in models and predictions. An important secondary component of the action will be to foster better, more dynamic two-way links between laboratory scientists studying processes at the most fundamental levels, and earth system scientists using large ensembles of such information as building blocks. The value of improved parameter data as a means to uncertainty reduction is also expressed in the EPHH theme and this action is complementary to the field programme in that theme. Additionally many field observation techniques begin life as laboratory instruments and the activity is an important feeder of new technology in this respect.

[1] Novel laboratory instrumentation will be implemented in conjunction with the technologies proof of concept action.

An illustration of potential world-leading science accessed through investment in this area is given below. The example gives three science areas opened up by the development of new experimental laboratory instrumentation to use a new 8-80 eV photon energy DLS beamline.

- Gas phase kinetics. Enhanced mass spectrometric detection of short lived intermediates using tuneable ionization source to differentiate between isomers. Accessing fundamental understanding of mechanisms from very small reactions (e.g. OH + CH_3CHO) through to larger systems such as dicarbonyl formation.
- Aerosol nucleation and analysis. Using tuneable synchrotron light sources to study nucleation of new aerosols *via* short wavelength light scattering and the properties and composition of aerosols *via* selective tuneable vacuum ultraviolet (VUV) synchrotron ionisation.
- Geochemical cycling and surface uptake. Key species undergoing surface deposition such as H_2SO_4, and HNO_3 are difficult to ionise. Developing instrumentation which uses tuneable synchrotron radiation would provide a sensitive ionization source for experiments at environmental concentrations.

Despite the fundamental importance of this underpinning research the UK capacity has been reduced in recent years. This has been driven in large part by the research being seen to fall between Research Councils, being both fundamental physical science and also environmental science. There is therefore a high degree of timeliness to the action, with the action playing an important capacity building role.

Implementation mechanisms.
This action will be enabled through a one-off investment delivered in conjunction with the Action 3 PoC call in 2009 via a research signpost activity. Up to £2M additional investment will be made in this strategic area supporting laboratory instruments for fundamental parameters projects falling within the envelope of the PoC mechanism. It is likely that many potential novel laboratory technologies that could be developed through this action will have cross-council relevance. The programme delivery will explore possible co-funding opportunities and collaborations with metrology centres. If a broad common technology development is proposed by multiple projects addressing differing topic areas, NERC will actively encourage the participation of an Industrial Technology partner for instrumentation delivery.

Potential Future Actions

Action 8. Next-generation climate models.
A joint action with Climate Systems on the development of next-generation climate models is proposed. Details are given in the Climate Systems TAP (action 6) along with details of the scoping activity planned at this stage. The need for a major technologies contribution to this joint action arises in part from the introduction of massively parallel computer architectures and the implementation of methods to aid prediction at a multitude of scales and the interactions between them. There are many competing new techniques for modelling the atmosphere with local refinement and it is not yet clear which will be most effective. The enabling of next-generation models will be guided strongly by the initial workshops proposed within Climate Systems, but with an emerging consensus from a technologies perspective for intercomparison exercises to test different modelling strategies as a forerunner to major model development activity.

Action 9. Networks of sensors – new technologies at the device level.
Relevant to many areas of environmental science there remain substantial limitations in performances of available sensor devices due to tradeoffs in sensitivity and selectivity that occur

with lower production cost methodologies. There is therefore a need to undertake technologies-led research which yields new sensors of appropriate chemical and biological sensitivity and selectivity, in addition to novel techniques to communicate with, operate and dynamically interact with data from large distributed networks. It is clear that 'the environment' is not always a high priority area for those working in the wider field of basic sensors research and some targeted activity is required to stimulate this.