Supporting Information (SI)

Expert Judgments about RD&D and the Future of Nuclear Energy

*Laura D. Anadon^a *, Valentina Bosetti^b, Matthew Bunn^a, Michela Catenacci^b, Audrey Lee^{a,c}*

^aHarvard University, John F. Kennedy School of Government, 79 John F. Kennedy Street, Cambridge, Massachusetts, 02138, United States

^bFondazione Eni Enrico Mattei, Corso Magenta 63, 20123, Milan, Italy

^cCalifornia Public Utilities Commission, 505 Van Ness Avenue, San Francisco, California, 94102, United States

*Corresponding author: laura_diaz_anadon@harvard.edu, tel.: (+1) 617-384-7325, fax: (+1) 617-495-8963

This Supplementary Information document contains fifteen pages (including this cover sheet), nine figures (Figures S1-S9), two tables (Tables S1 and S2), references, and is divided into the following sections:

SI Section	Page
S1. List of the 60 E.U. and U.S. Nuclear Experts Who Participated in this Study	S2
S2. Expert Elicitation Instrument	S3
S3. Additional Comments on Expert Elicitation Instrument Design	S3
S4. Brief Analysis of Cognitive and Motivational Biases	S5
S5. Insights from the Methodology	S6
S6. Results on Overnight Capital Cost for Gen III/III+ and SMRs	S8
S7. Returns to RD&D Results	S9
S8. Distribution of Nuclear RD&D Budget Recommendations	S10
S9. Additional Discussion on RD&D Thrusts and Gen. IV Reactor Systems	S10
S10. Results on Nuclear Plant Risk Premium Compared to Natural Gas Plants	S11
S11. Results on Constraints on Future Nuclear Energy Growth	S12
S12. Results on the Impact of Fukushima on Experts' Opinions	S15
SI References	S15

S1. List of the 60 E.U. and U.S. Nuclear Experts Who Participated in this Study

Table S1: Experts who participated in the online survey; in grey, experts who participated in the workshop.

Name	Previous and/or current affiliation	Country	Name	Previous and/or current affiliation	Country
<i>Markku Anttila</i>	VTT (Technical Research Centre of Finland)	Finland	<i>John F. Ahearne</i>	National Academy of Sciences, Sigma Xi, Nuclear Regulatory Commission	USA
<i>Fosco Bianchi</i>	Italian National Agency for New Technologies, Energy & Sustainable Economic Development (ENEA)	Italy	<i>Johnhong Ahn</i>	University of California, Berkeley	USA
<i>Luigi Bruzzi</i>	University of Bologna	Italy	<i>Edward D. Arthur</i>	Advanced Reactor Concepts, Los Alamos National Laboratory, University of New Mexico	USA
<i>Franco Casali</i>	ENEA; IAEA; University of Bologna	Italy	<i>Sydney J. Ball</i>	Oak Ridge National Laboratory	USA
<i>Jean-Marc Cavedon</i>	Paul Scherrer Institut	Switzerland	<i>Ashok S. Bhatnagar</i>	Tennessee Valley Authority Nuclear Operations	USA
<i>Didier De Bruyn</i>	SCK CEN, the Belgian Nuclear Research Centre	Belgium	<i>Robert J. Budnitz</i>	Lawrence Berkeley National Laboratory, Nuclear Regulatory Commission	USA
<i>Marc Deffrennes</i>	European Commission, DG TREN, Euratom	Belgium	<i>Douglas M. Chapin</i>	MPR Associates	USA
<i>Allan Duncan</i>	Euratom, UK Atomic Energy Authority, HM Inspectorate of Pollution	United Kingdom	<i>Michael L. Corradini</i>	University of Wisconsin-Madison	USA
<i>Dominique Finon</i>	Centre National de la Recherche Scientifique (CNRS), Centre International de Recherche sur l'Environnement et le Développement	France	<i>B. John Garrick</i>	U.S. Nuclear Waste Technical Review Board	USA
<i>Konstantin Foskolos</i>	Paul Scherrer Institut	Switzerland	<i>Michael W. Golay</i>	Massachusetts Institute of Technology	USA
<i>Michael Fuetterer</i>	Joint Research Centre - European Commission	The Netherlands	<i>Eugene S. Grecheck</i>	Dominion Energy	USA
<i>Kevin Hesketh</i>	UK National Nuclear Laboratory	United Kingdom	<i>Pavel Hejzlar</i>	TerraPower	USA
<i>Christian Kirchsteiger</i>	European Commission, DG Energy & Transport	The Netherlands	<i>J. Stephen Herring</i>	Idaho National Laboratory	USA
<i>Peter Liska</i>	Nuclear Power Plants Research Institute	Slovak Republic	<i>Thomas Isaacs</i>	Stanford University, Lawrence Livermore National Laboratory	USA
<i>Bruno Merk</i>	Institute of Safety Research Forschungszentrum Dresden-Rossendorf	Germany	<i>Kazuyoshi Kataoka</i>	Toshiba	USA
<i>Julio Martins Montalvão e Silva</i>	Instituto Tecnológico e Nuclear	Portugal	<i>Andrew C. Klein</i>	Oregon State University	USA
<i>Stefano Monti</i>	Italian National agency for new technologies, Energy and sustainable economic development (ENEA)	Italy	<i>Milton Levenson</i>	Oak Ridge National Laboratory, Bechtel, EPRI	USA
<i>William Nuttall</i>	University of Cambridge	United Kingdom	<i>Regis Matzie</i>	Westinghouse	USA
<i>Francois Perchet</i>	World Nuclear University	United Kingdom	<i>Andrew Orrell</i>	Sandia National Laboratory	USA
<i>Enn Realo</i>	Radiation Safety Department, Environmental Board, Estonia; University of Tartu	Estonia	<i>Kenneth L. Peddicord</i>	Texas A&M University	USA
<i>Hans-Holger Rogner</i>	International Atomic Energy Agency (IAEA)	Austria	<i>Per F. Peterson</i>	University of California, Berkeley	USA
<i>David Shropshire</i>	Joint Research Centre - European Commission	The Netherlands	<i>Paul S. Pickard</i>	Sandia National Laboratory	USA
<i>Simos Simopoulos</i>	National Technical University of Athens; Greek Atomic Energy Commission, NTUA	Greece	<i>Burton Richter</i>	Stanford University, Lawrence Livermore National Laboratory	USA
<i>Renzo Tavoni</i>	Italian National agency for new technologies, Energy and sustainable economic development (ENEA)	Italy	<i>Geoffrey Rothwell</i>	Stanford University	USA
<i>Andrej Trkov</i>	Institute Jozef Stefan	Slovenja	<i>Pradip Saha</i>	GE Hitachi Nuclear Energy	USA
<i>Harri Tuomisto</i>	Fortum Nuclear Services Oy	Finland	<i>Craig F. Smith</i>	Lawrence Livermore National Laboratory, Monterey Naval Postgraduate School	USA
<i>Ioan Ursu</i>	Horia Hulubei National Institute of Physics and Nuclear Engineering (IFIN-HH)	Romania	<i>Finis Southworth</i>	Areva North America	USA
<i>Bob van der Zwann</i>	Energy Research Centre of the Netherlands (ECN)	The Netherlands	<i>Temitope Taiwo</i>	Argonne National Laboratory	USA
<i>Georges van Goethem</i>	European Commission, DG Research, Euratom	Belgium	<i>Neil E. Todreas</i>	Massachusetts Institute of Technology	USA
<i>Simon Webster</i>	European Commission, DG Energy, Euratom	Belgium	<i>Edward Wallace</i>	NuScale, PBMR Ltd., Tennessee Valley Authority	USA

S2. Expert Elicitation Instrument

Link to U.S. nuclear elicitation survey: https://erd3energystudy.org/KSG_forms/index.php

Username: ES&T

Password: TtfHyx

Link to E.U. nuclear elicitation survey: <https://erd3energystudy.org/icarus/index.php>

Username: ES&T

Password: tgk5Fe

S3. Additional Comments on Expert Elicitation Instrument Design

To reduce bias in the experts' estimates, the introductory section of the elicitation was designed to train the experts on probability and bias concepts. Specific response modes—in particular the use of percentiles to capture uncertainty versus the probability of meeting certain cost goals, the graphic supports for the relationship between cost and RD&D levels, as well as uncertainties in estimates and experts' budget allocations—were chosen to facilitate a speedy completion and correct interpretation of the elicitation. The feedback from experts on these visual tools was positive. After experts completed the online elicitation, experts received a summary of the answers of all participating experts, giving them a chance to provide feedback.

The left panel in Figure S1 summarizes the structure of the process followed to conduct the surveys. The right panel shows a structure of the online elicitation instrument.

Experts' judgments can be influenced by clarity and survey design, as well as by motivational biases caused by incentives or pressures that lead people to provide answers that do not entirely reflect their beliefs. Sources of motivational biases can include, for example, social pressure, from the interviewer or from the group of experts ("group think"). The on-line questionnaires allowed us to avoid the group-think bias. The group workshop allowed us to verify the online survey findings, discussing areas where experts may have had different interpretations of the questions, and allowing the experts to modify their views through discussion and debate.

The elicitation instrument included several graphic displays to help experts visualize their answers. For example, experts were able to see their 10th, 50th, and 90th percentile estimates of cost for different RD&D levels in a single graph and had 100 chips (representing percentages of their recommended RD&D investment) that they could allocate in a "board game" that included different nuclear technology areas and innovation stages. The design of the survey involved several choices, including expert selection, the mode of the survey, the structure of the elicitation, the visualization of the answers, and the phrasing of the questions, among others. These choices were made over a couple of months with the help of two nuclear experts, who tested the surveys and provided feedback on everything from terminology to the appropriateness and clarity of questions and the tool.

Figure S1: (a) Structure protocol employed in the design of the online elicitation and group discussion; (b) structure of the individual online elicitation instrument.

All question formats have their advantages and disadvantages, and there is no agreement regarding the best way of phrasing these questions. In our case, it was necessary to keep the survey to a manageable length (it already took experts over 2 hours to complete it). Within these limitations, we chose a Likert scale to frame the question about the non-cost benefits of RD&D; the literature suggests that this approach is preferable to “forced choice” responses (i.e., true/false) in most cases (38). In addition, we had short responses and an odd number (5) of response choices, since the literature indicates that Likert scales should be odd-numbered whenever they represent a categorical variable, and should, all other things being equal, be shorter rather than longer (38). We also defined the five points in the scale quantitatively to ensure consistency in interpretation among experts. Below are the definitions of the five points in the scale that were provided to each expert in the survey:

- 1 = inability to address goal **would not significantly constrain** the deployment of additional nuclear facilities in 2030-2050 (less than 10% lower).
- 2 = inability to address goal **would slightly constrain** the deployment of nuclear facilities (between 10-40% lower).
- 3 = inability to address goal **would moderately constrain** the deployment of nuclear power capacity from 2030-2050 (between 40-60% lower).
- 4 = inability to address goal **would significantly constrain** the deployment of nuclear power capacity from 2030-2050 (between 60-90% lower).
- 5 = inability to address goal **would greatly constrain** the deployment of additional nuclear facilities in 2030-2050 (at least 90% lower).

This definition of the points on the scale allowed us to capture the experts' judgments of RD&D's potential benefit in addressing constraints on the future growth of nuclear energy. If, however, some experts thought that improvements in a particular factor such as safety would not have great impacts on the future growth of nuclear energy but would reduce the risks of that growth, this benefit might not show up clearly in this scale.

S4. Brief Analysis of Cognitive and Motivational Biases

The online survey was designed to minimize the occurrence of cognitive biases in the experts' probability estimates. Biased estimates might result, for example, from the heuristic procedure of "availability" (linked to the ease with which experts could imagine an event occurring), from the "anchoring effect" (by which the experts might choose an initial anchor and then adjust their estimates around it), or from the "representativeness" of an event (which can sometimes influence its judged probability) (SI Ref. 1). Experts are also often overconfident in the precision of their estimates, underestimating their uncertainty. To address these biases, our survey instrument (available in its entirety online using the information provided in S2 in this SI) included, among other things: (a) a section encouraging experts to think about the lowest possible and highest possible costs and about the range of events that may affect costs before asking them to introduce their 50th, 10th, and 90th percentiles; (b) a background information section to ensure that experts had a range of information available to them to help them overcome anchoring (though the background information could have also provided a common set of anchors, most experts projected costs that were higher than those presented in the background section, indicating that the experts did not anchor strongly on the numbers presented in the background information); and (c) a section explaining overconfidence with a historical example of overconfidence in estimates. Our survey instrument did not directly address availability and representativeness biases in matters such as estimating the risk of an accident or of a terrorist attack, but it is notable that the Fukushima accident, which surely dramatically increased the mental availability of major accidental radiation releases, had only a modest effect on most experts' estimates of the nuclear future or the future risk of further accidents. This may suggest that availability bias was not a major driver of their initial estimates. We comment on Fukushima's impact on the experts' estimates in section S12 of this SI.

Among other sources of bias, the experts' background and expertise is obviously a key driver of their judgment. Motivational biases could have come into play if experts thought that recommending large amounts of RD&D funding for their areas may result in more funds for research in their area. To determine whether experts consistently recommended larger RD&D

investments for their areas of expertise, we included a section in the survey asking experts to rate their level of expertise on different reactor technologies and cross-cutting research areas. For E.U. experts there is a low and negative Pearson's correlation (-0.41) between high expertise in an area and high budget allocation. For U.S. experts, the correlation is positive but low (0.2). In short, it does not appear that the experts allocated substantially more RD&D spending to their own areas of expertise.

S5. Insights from the Methodology

The two-step procedure, soliciting experts individually and then following up in a group discussion, made it possible to identify key issues that could arise when each of the two methodologies is followed as a stand-alone procedure and was a relatively cost-efficient protocol.

There are aspects of the individual remote surveys that the workshop helped clarify:

- *Verification of the online expert elicitation results on costs and performance.* Experts participating in the workshop were asked about the clarity of the questions (particularly their answers about the probability of cost and performance for different RD&D scenarios) and given the opportunity to change their answers. Few U.S. and E.U. experts made changes to their cost answers, and these changes were minimal: one U.S. expert revised his Gen. III/III+ BAU cost estimates slightly upward, another U.S. expert revised his Gen. IV cost estimates (also slightly upward), and another U.S. expert revised his BAU SMR cost estimate slightly downward. Two E.U. experts revised their Gen. III/III+ costs slightly (one up and one down), two E.U. experts revised their Gen. IV costs slightly (one up and one down), and one E.U. expert revised his SMR cost estimate downward. These changes were minor and were a response to new information that became available between the time when experts filled out the individual survey and the workshop, which occurred in the backdrop of the Fukushima nuclear accident in March 11, 2011. The discussion at the workshop itself did not appear to lead to significant changes in experts' projections.
- *Impact of Fukushima on the future of nuclear deployment in the United States and the European Union.* In contrast with the cost estimates, which remained largely unchanged after the workshop, E.U. and U.S. experts adjusted the probabilities that they had assigned to three scenarios for the future of nuclear power in their region, as discussed below.
- *Impact of workshop discussion on individual judgments on nuclear RD&D thrusts.* The discussion at the workshop appears to have contributed to increased consensus among the experts on RD&D allocation. RD&D areas that gained in importance after the U.S. and E.U. experts revised their answers were SMRs, risk and safety, and proliferation resistance. E.U. experts also increased their recommended allocations for SFRs and fuels and materials, while reducing the allocations for MSRs and fuel cycle technologies. U.S. experts allocated slightly lower shares of RD&D investments during the workshop to SCWRs, VHTRs, and SFRs.
- *Improved understanding of how some experts perceived questions about events.* While experts displayed a clear understanding of the questions asked about costs and performance, during the workshop it became clear that different experts were using a different definition of

“major radioactivity releases caused by an accident or sabotage” when asked about the impact that such an event would have on the growth of nuclear power, and the probability of such an event occurring. While some thought that the Fukushima accident would fall under their definition of a “major radioactivity release,” others felt that such a description would only apply to a larger accident with more direct casualties.

- *Improved understanding of motivations behind experts’ RD&D recommendations.* The discussion at the workshop revealed that while some experts thought of climate change mitigation as the main goal when making RD&D recommendations, others had multiple goals in mind. This variation in the experts’ reasoning would not have been revealed had we pursued only the individual elicitations.
- *Clarity on reasons behind differences between the emphasis of E.U. and U.S. experts.* U.S. experts place more emphasis on RD&D to clarify fuel cycle economics and reduce fuel cycle costs than E.U. experts do. During the workshop experts explained that this is likely to be caused by the fact that in the United States there is a greater focus on private sector involvement. Large-scale fuel cycle facilities would likely not be built in the United States unless private firms believed it was profitable to do so, while in Europe such activities might be undertaken by state-owned firms or with other state support.
- *New insights on differences of opinion between U.S. and E.U. experts.* Even though the ranges of estimates of the future costs of SMRs were similar between experts across the Atlantic, E.U. experts thought it unlikely that a substantial market for SMRs would develop, while U.S. experts were split between SMR market optimists and skeptics. There are several reasons for this, including the fact that financing GW-scale nuclear power plants in the United States may be more difficult than in some European countries which may have government involvement in nuclear financing.

As stated earlier, while insights on costs did not change during the workshop from the individual expert elicitations, the workshop enriched the information obtained from the elicitations on other topics.

S6. Results on Overnight Capital Cost for Gen III/III+ and SMRs

Figures S2 and S3 present the expert estimates for Gen. III/III+ and SMR reactors respectively.

Figure S2: Gen. III/III+ overnight capital cost estimates of U.S. (top panel) and E.U. (bottom panel) experts in 2010 (gray squares), 2030 under BAU RD&D (black squares), 2030 under recommended RD&D (black square outlines), and 10th and 90th percentile error bands (vertical lines). The range of AFC Cost Basis estimates is also provided for comparison (horizontal lines in gray) (SI Ref. 2). Data also presented in SI Ref. 3.

Figure S3: SMR 2030 overnight capital cost estimates of U.S. (top panel) and E.U. (bottom panel) experts under BAU RD&D (black squares) and under recommended RD&D (black square outlines). 10th and 90th percentile error bands (vertical lines). Data also presented in SI Ref. 3.

S7. Returns to RD&D Results

Figure S4 shows that experts expect decreases in overnight capital cost of the three systems investigated resulting from RD&D alone, excluding learning-by-doing in building subsequent plants.

Figure S4: Impact of RD&D investments on the overnight capital cost reduction in 2030 of Gen. III/III+ plants (triangles, top panel), Gen. IV plants (diamonds, middle panel), and small modular reactors (squares, bottom panel). Note that the cost reductions are associated with RD&D investment in either the United States or the European Union as a whole.

Table S2 shows the results of the returns to RD&D regressions.

Table S2: Estimated impact of public RD&D to reduce overnight capital costs in 2030 when compared to costs in 2030 under a BAU public RD&D funding level.

Parameter	Gen. III/III+	Gen. IV	SMR
Returns to R&D rate	1.36%	5.13%	5.11%
p-value	0.001	0.000	0.000
R ²	0.1065	0.2644	0.2714

S8. Distribution of Nuclear RD&D Budget Recommendations

Figure S5 shows the recommended investments in annual public nuclear RD&D investments for the European Union and the U.S. federal government from E.U. and U.S. experts, respectively.

Figure S5: Distribution of experts' recommended total RD&D budget to nuclear energy.

S9. Additional Discussion on RD&D Thrusts and Gen. IV Reactor Systems

Experts were also asked to write down the RD&D objectives they intended to achieve in the four areas to which they devoted the largest amount of funds. Here we provide some of the key objectives and differences between U.S. and E.U. experts.

Experts devoting significant funds to SMRs described several benefits to these investments, including: less lumpy capital investments, the possibility to achieve economies of scale in manufacturing (to possibly outweigh the loss of economies of scale in power generation), increased siting flexibility, a reduction in construction times, and the possibility of recycling existing sites. US experts emphasized the need for support for demonstration and safety testing, while E.U. experts emphasized the need for longer-term R&D on fuels and materials that would enable particular types of SMRs.

U.S. experts recommending large amounts of funds for fuel cycle research emphasized research to improve economics, while E.U. experts emphasized waste minimization. Both U.S. and E.U. experts mentioned separation chemistry of minor actinides and research on spent fuel geologic disposal and high-level waste repositories as important RD&D objectives.

Both U.S. and E.U. experts emphasized research on materials for reactor cores, valves, pumps, intermediate heat exchangers, etc. (e.g., ceramic composites and nanomaterials); fuels to withstand extreme temperatures and high-radiation fields; and research on improved simulation codes.

Each Gen. IV reactor type is said to have different advantages. In essence, the fast reactors have the ability to breed more plutonium (or U-233) than they consume, so if limited uranium resources are a major concern, they could help address that problem. But it will probably be many decades, and perhaps longer, before uranium supplies become limited enough for this to be

a major driver of reactor deployment choices. Fast reactors also have the potential for improved transmutation of long-lived radionuclides, possibly easing the waste management problem. The sodium-cooled fast reactor is the most popular of the fast reactors because there is the most experience with it, and sodium has some desirable properties as a coolant. The lead-cooled or gas-cooled fast reactors could get the uranium-resource extension of fast reactors without sodium's fire risks — but with new problems for their coolants. The high-temperature gas reactor offers the possibility of increased inherent safety (including the ability to survive a cutoff of all cooling without melting down). That system also goes to very high temperatures, which increases efficiency and offers the opportunity to provide high-temperature process heat, which could improve overall economics. The molten salt reactor has no solid fuel (so no fuel fabrication costs and no danger of fuel melting), and offers the opportunity to separate out a portion of the fission products on each cycle, breeding uranium or plutonium without ever separating out weapons-usable nuclear material from the rest of the molten salt.

As shown in Figure S6, U.S. experts are generally more optimistic regarding the commercialization date of Gen. IV systems.

Figure S6: Time when a Gen. IV nuclear plant or system will first become commercially available under the RD&D scenario proposed by expert.

S10. Results on Nuclear Plant Risk Premium Compared to Natural Gas Plants

Experts were asked to evaluate the risk premium for nuclear power facilities over that of natural gas power plants. Risk premium is the financial return in excess of the risk-free rate that a riskier investment is expected to yield, to attract capital from investors.

As shown in Figure S7, most experts thought that, in the short term (around 2010 or the present time), nuclear projects would have to pay a substantial risk premium compared to natural gas-fired power projects, to account for factors such as possible delays, cost over-runs, or project cancellations. As time goes on, however, most experts expect this risk premium to decline (though not to zero). Some of the estimates of the risk premium by E.U. experts appear unrealistically high (at 20-50%, they are higher than most estimates of the *total* capital charge for financing nuclear plants); these experts may have interpreted the question as referring to the fractional increase in the capital charge, so that if the financial return required for nuclear energy was 12% rather than 10% for natural gas (a 20% higher figure), the risk premium would be 20%.

Given that financing costs are a key factor undermining the competitiveness of nuclear energy, it is striking that these nuclear technology experts, almost all of whom are nuclear energy advocates, overwhelmingly predicted that as far in the future as 2050, nuclear energy would still be considered a somewhat riskier investment than other types of electric power.

Figure S7: Risk premium for nuclear investment above natural gas power plant discount rate according to E.U. experts (above) and U.S. experts (below). Data also presented in SI Ref. 3.

S11. Results on Constraints on Future Nuclear Energy Growth

A wide range of factors could affect the future of nuclear energy, only some of which are susceptible to being addressed by RD&D investments. We therefore asked experts about what factors and what future events would be most important in promoting or constraining nuclear energy growth, and about the probability of different future growth scenarios *in their regions*. (Our survey did not ask the experts to judge the likelihood of different scenarios for *global* nuclear energy deployment; this would be a useful area for further research.)

Overwhelmingly, the negative future event that the participating experts expected would have the largest impact on nuclear energy growth was an accident or terrorist attack somewhere in the world leading to a major radioactive release. Both U.S. and E.U. experts generally estimated that such an event would reduce future deployment in their region by 50-100%. Most experts, however, judged the probability of such an event occurring anywhere in the world to be 10% or less over the next 20 years. (Only one expert participating in the workshop changed his estimate on this point after Fukushima.)

The other events the participating experts believed would have the largest negative impact were major cost overruns in nuclear projects or a cascade of proliferation perceived as resulting from the civilian nuclear energy system. Many experts believed that major cost overruns were fairly likely (with roughly half of the experts putting the likelihood of such overruns above 50%). Both U.S. and E.U. experts thought that successful siting and operation of nuclear waste

repositories in the United States and in other countries would be a major step forward for nuclear energy, increasing likely growth significantly, and both thought such successes were fairly likely, with other countries being even more likely to succeed than the United States (see Figure S8).

Figure S8: Figure S8a shows the percentage change in future nuclear growth in their region U.S. and E.U. experts project would result from various future events. Figure S8b shows the experts' judgment as to the probability of those events. The numbers in each box are the number of experts providing that rating; ratings with the largest concentrations of experts are shaded. Data also presented in SI Ref. 3.

Figure S9: Experts' probabilities for different diffusion scenarios in 2050 (top panel for E.U. experts, bottom panel for U.S. experts). For the U.S. experts, the three scenarios evaluated are: Low: maintaining current U.S. nuclear power capacity (100.6 GWe) in 2050; Medium: 286 GWe of U.S. nuclear capacity in 2050 (which corresponds to the low scenario of MIT's 2003 *Future of Nuclear Power* report (SI Ref. 4)); 477 GWe of U.S. nuclear capacity in 2050 (the high scenario of MIT's 2003 *Future of Nuclear Power* report). For the E.U. experts, the three scenarios evaluated are: Low: maintaining current E.U. nuclear power capacity (170 GWe) in 2050; Medium: 280 GWe of E.U. nuclear capacity in 2050 (half the growth rate of the IAEA 2006 *Energy, Electricity and Nuclear Power Estimates* (SI Ref. 5)); High: 400 GWe of E.U. nuclear capacity in 2050 (the growth rate of the IAEA 2006 *Energy, Electricity and Nuclear Power Estimates*).

On average, the participating experts were cautiously optimistic about future nuclear energy growth in their regions, though there were sharp differences of view. When presented with a low (no growth), medium, and high scenario for nuclear growth in their regions, only a few thought the probability of the low scenario was 70% or more, but there were also only a few who thought it could be ruled out. The same held for the high-growth scenario. The medium scenario (defined as 280-290 GWe of nuclear capacity installed by 2050 both in the United States and in the European Union) had the highest probability estimate, averaging across all the experts. Overall, the vast majority of both U.S. and E.U. experts projected that it was more likely than not

that nuclear energy would achieve either medium or high growth in their regions by 2050 (see Figure S9).

S12. Results on the Impact of Fukushima on Experts' Opinions

Participating experts provided their on-line responses well before the Fukushima accident, while the workshop took place four weeks after the accident began. Experts participating in the workshop had an opportunity to discuss their answers and the issues arising from the Fukushima accident in-depth, and were given an opportunity to modify their previous judgments if they so chose. Only a few experts chose to modify their projections of nuclear power costs or their recommendations with respect to nuclear RD&D investments. Both E.U. and U.S. experts, however, adjusted their projections for nuclear power growth after Fukushima. Three out of the six U.S. experts participating in the workshop reduced their estimates of the probability of high nuclear growth – from 60% to 30% in two cases and from 35% to 20% in another case. One of the remaining three U.S. experts adjusted his probability for the high growth scenario slightly *upward*, from 35% to 40%. Four of the twelve E.U. experts participating in the workshop cut their estimates of the probability of high growth – from 45%, 60%, 20%, and 30% to 20%, 50%, 10%, and 10%. The experts participating in the workshop generally agreed that (a) as of late April 2011, it was too soon to draw many of the lessons from Fukushima until more was understood; (b) there would inevitably be tightened regulation in several areas and increased emphasis on safety; and (c) with appropriate government investment and support, nuclear power could still achieve large-scale global growth by 2050. The participating experts argued that while a few existing nuclear power countries (such as Germany) might change course, and some “newcomer” countries considering their first plant might reconsider, the largest nuclear markets (such as China) were likely to continue on a path of substantial growth.

The discussion at the workshop appears to have contributed to increased consensus among the experts on RD&D allocation. RD&D areas that gained in importance after the U.S. and E.U. experts revised their answers were SMRs, risk and safety, and proliferation resistance. E.U. experts also increased their recommended allocations for SFRs and fuels and materials, while reducing the allocations for MSR and fuel cycle technologies. U.S. experts allocated slightly lower shares of RD&D investments during the workshop to SCWRs, VHTRs, and SFRs.

SI References

(SI Ref. 1) Tversky, A.; Kahneman, D. Judgment under uncertainty: Heuristics and biases. *Science*, 1974, 185:1124-1131.

(SI Ref. 2) Shropshire, D. E.; Williams, K. A.; Hoffman, E. A.; Smith, J. D.; Hebditch, D. J.; Jacobson, J. J.; Morton, J. D.; Phillips, A. M.; Taylor, J. P. *Advanced Fuel Cycle economic analysis of symbiotic light-water reactor and fast burner reactor systems*. Technical Report from the Idaho National Laboratory. Document INL/EXT-09-15254, U.S. Department of Energy, Washington D.C., United States. January 2009.

(SI Ref. 3) Anadon, L.D.; Bosetti, V.; Bunn, M.; Catenacci, M.; Lee, A. International Workshop on Research, Development, and Demonstration to Enhance the Role of Nuclear Energy in Meeting Climate and Energy Challenges. Report for Energy Technology Innovation Policy research group, Belfer Center for Science and International Affairs, Harvard Kennedy School,

ICARUS Project, Fondazione Eni Enrico Mattei, and International Center for Climate Governance, April 2011.

(SI Ref. 4) MIT. The Future of Nuclear Power- An Interdisciplinary MIT Study. Massachusetts Institute of Technology. Cambridge, Massachusetts, United States. 2003.

(SI Ref. 5) IAEA. Energy, Electricity, and Nuclear Power Estimates for the period up to 2030. (International Atomic Energy Agency. Vienna, Austria). July 2006.