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Plutonium Worlds. Fast Breeders, Systems Analysis and Computer Simulation in the Age of Hypotheticality

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This article examines the media history of one of the hallmark civil nuclear energy programs in Western Germany – the development of Liquid Metal Fast Breeder Reactor (LMFBR) technology. Promoted as a kind of perpetuum mobile of the Atomic Age, the "German Manhattan Project" not only imported big science thinking. In its context, nuclear technology was also put forth as an avantgarde of scientific inquiry, dealing with the most complex and 'critical' technological endeavors. In the face of the risks of nuclear technology, German physicist Wolf H√§fele thus announced a novel epistemology of
"hypotheticality". In a context where traditional experimental engineering strategies became inappropiate, he called for the application of advanced media technologies: Computer Simulations (CS) and Systems Analysis (SA) generated computerized spaces for the production of knowledge. In the course of the German Fast Breeder program, such methods had a twofold impact. One the one hand, H√§fele emphazised – as the "father of the German Fast Breeder" – the utilization of CS for the actual planning and construction of the novel reactor type. On the other, namely as the director of the department of Energy Systems at the International Institute for Applied Systems Analysis (IIASA), H√§fele advised SA-based projections of energy consumption. These computerized scenarios provided the rationale for the conception of Fast Breeder programs as viable and necessary 'alternative energy sources' in the first place. By focusing on the role of the involved CS techniques, the paper thus investigates the intertwined systems thinking of nuclear facilities's planning and construction and the design of large-scale energy consumption and production scenarios in the 1970s and 1980s, as well as their conceptual afterlives in our contemporary era of computer simulation.

Keywords: Computer Simulation, Systems Analysis, Scenario Building, Trial and Error, Fast Breeder Reactor, Epistemology, Atomic Age, Media History

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Wolf in Wonderland

Located in a sparsely populated region not far from the border to the neighboring Netherlands, the small German town of Kalkar could well have remained in a state of comfortable oblivion. As the city's website tells its visitors, Kalkar preserved a touch of medieval charm from its founding years in the 1230s and had his heydays in the 15th century – followed by a rapid decline in the 16th century. However, after having fallen into a 500-years-long Rip van Wrinkle sleep, Kalkar was woken up by a belated and unexpected *wirtschaftswunder* at the beginning of the 1970s. Typical for sparsely populated and structurally backward regions, it became the object of quite dubious governmental and business games. Sometimes, such regional development initiatives result in the establishment of provincial airports or amusement parks, sometimes in industrial parks or – at least in 1970s Western Germany – even in the set-up of nuclear power plants. And in some especially illustrious cases two of these possible advancements overlap. Kalkar just happens to be such a case, effected by the construction and history of Germany's first large-scale Liquid Metal Fast Breeder Reactor (LMFBR) *SNR-300*. The project, being promoted as a kind of *perpetuum mobile* of the Atomic Age, and thus funded with about 7 Billion Deutsche Mark (DM), initially was the reason for Kalkar's delayed economic miracle. But from the start it became clear that SNR-300 – the number indicated the intended power output of 300 Megawatts – was challenged by tremendous technical predicaments. And from the mid-1970s onwards, it also faced fierce resistance as the German public grew more and more critical and sensitive on nuclear technology. Completed in 1985, the Fast Breeder was set in 'partial operation'. The cooling systems run for years, but the plant never received nuclear material and hence did not produce energy. Finally, on March 21, 1991, former Bundesforschungsminister Heinz Riesenhuber announced the termination of the LMFBR. And as an effect, the remains of this epitome of FRG's nuclear technology were bargained to a Dutch scrap merchant and investor for the alleged amount of 2,5 Million DM. Since then, the site drags out its afterlive as an amusement park called *Wunderland Kalkar*, with its brute, up to 93 meters tall concrete architecture and its mascot 'Kernie' as eerie remembrances of its past.

The paper examines the SNR-300 project from a historical and epistemological media studies perspective. It is conceptually situated in a specific context of New German Media Theory[1] which explores the epistemic impact of (novel) media technologies in different scientific fields. In this line of thoughts the case study thus concretely investigates the implementation of a novel epistemology in

[1] See *Grey Room 29: New German Media Theory*, ed. Eva Horn (Cambridge: MIT Press 2007)

nuclear sciences. In the face of the involved highly dangerous nuclear processes, uncertainties and scaling effects in civil nuclear energy projects, traditional experimental and engineering approaches became utterly inadequate. The LMFBR programs called for media technologies which would provide a space for 'virtual experimentation' – and this call was met by computer simulations. The hypothesis of this article is that the German LMFBR program is informative for a conception of an afterlife of systems in a twofold way: First, the SNR-300's techno-history can be perceived as an outstanding example for an era in which some apostles of civil nuclear energy production portrayed nuclear technology as the avantgarde of scientific research. Western Germany's physicist and 'father of the Fast Breeder', Wolf Häfele, celebrated the leading-edge status of nuclear technology precisely because it had to deal with inevitable uncertainties: For Häfele, the Atomic Age was characterized by a thorough "hypotheticality": "The process of iteration between theory and experiment which leads to truth in its traditional sense is no longer possible. Such truth can no longer be fully experienced. This means that arguments in the hypothetical domain necessarily and ultimately remain inconclusive".[2] When traditional methods of experimenting and modelling became inappropriate, and when a conventional, experimental trial-and-error-based knowledge production was entirely prohibitive because of the involved nuclear endangerments, Häfele demanded an epistemology which was able to describe the modes of the 'hypothetical domain.' Due to the fact that the 'test mode' of a facility like a Fast Breeder was always at the same time the 'case of emergency', the construction, risk management, and control of LMFBRs required the development and employment of CS. These opened up extended knowledge spaces as virtual experimenting and testing grounds and provided a synthetic perspective on multiple non-linear dynamics in the planning and engineering of such highly complex systems.

Second, the application of computer simulations in the technical planning and operational set-up of power plants strongly relates to yet another computer simulation paradigm. In 1973, Wolf Häfele also became director of the department of Energy Systems at the newly founded *International Institute for Applied Systems Analysis* (IIASA) in Laxenburg, located closely to the Austrian capital of Vienna. Building upon social simulations in the tradition of *systems analysis* – the most prominent at that time had been Jay W. Forrester's modellings for David Meadows's epochal publication *The Limits to Growth* – Häfele's working group developed possible (world-wide) energy production scenarios. Thereby, it depicted the indispensable role of nuclear technology for an endurable planetary future. While contemporary critics described these as obnoxious 'plutonium

[2] Wolf Häfele, "Hypotheticality and the New Challenges," in *Facing up to Nuclear Power*, ed. John Francis and Paul Albrecht (Edinburgh: St Andrews Press, 1976), 55.

worlds' (Robert Jungk) which would ruin the future of all mankind and called for a complete change of direction in the assessment of nuclear energy, these CS scenarios nevertheless provided the rationale for the extended engagement in 'avant-garde technologies' like Fast Breeders.

The article thus investigates the intertwined system thinking of two CS paradigms: On the one hand, nuclear facilities' planning and construction, and on the other the design of large-scale energy consumption and production scenarios in the 1970s and 1980s. This perspective not only enables a critical evaluation of the afterlife of such systems in actual 'sustainable' energy production models and simulations. It also argues that in a time of hypothetical thinking and research strategies, the technocratic vanguards of the Atomic Age simply forgot to include one paramount factor into their simulation scenarios which – at least in Western Germany – finally brought their systems thinking to the fall: That is, the incorporation of social and political acceptance.

The German Manhattan Project

Wolf Häfele was involved in the development of the SNR-300's technology in leading positions since the beginning of the 1960s. As a speaker of the early German Fast Breeder research projects KNK-I and II (Compact Natrium-Cooled Nuclear Facility Karlsruhe), he realized that the successful implementation of Big Science depended on professional marketing and political lobbying strategies. It was not a coincidence that he referred to the US-American *Manhattan Project* when promoting the German Fast Breeder program. In order to organize a giant leap forward on contemporary high-tech terrain, Häfele announced an era of "project science" in the FRG. His "German Manhattan Project"[3] was designed to catch up with other industrialized countries after years of restrictions regarding nuclear technologies which followed World War II – or to even outperform these countries. As the heart of a 'sustainable' nuclear energy production system, the development of LMFBRs thus can be seen as a birthplace of big science in Germany. According to a critical review in the news magazine *Der Spiegel* in 1981, Häfeles project thereby turned former research logics upside down: It would first define the desirable results, and then start to initialize the means and the research initiatives to achieve these outcomes. At the same time, the advocates of nuclear science asserted that the program would put the country in a global leadership role for the mastering of future energy needs of industrialized societies in the face of diminishing natural resources.

[3] See Werner Mayer-Larsen: "Der Koloss von Kalkar" In: *Der Spiegel* 43 (1981), 42-55.

But Häfele not only emphasized the need for thinking big (science). He also underlined the epistemological "pathfinder role" of nuclear technologies for scientific thinking as such. For the 'Breeder-Professor', the relevant questions for science consisted of describing complex relations and contingent events and – incorporated as the research in nuclear technologies – had to leave behind classical epistemic strategies:

> The traditional engineering approach to eliminating risks […] which are integral to contingency – is trial and error. The engineer learns by experience to make better and safer machines. This is close to the scientific approach: a hypothesis is made which is followed by experiments, which in turn lead to an improved hypothesis, which again is followed by experiments. In this way a theory evolves which is true, i.e. is in touch with reality […]. It is precisely this interplay between theory and experiment, or trial and error, which is no longer possible for new technologies which are designed to master unique challenges.[4]

The SNR-300 project exemplarily illustrates the epistemological layout of this novel practice of scientific inquiry: As soon as nuclear technologies transform from notes on paper to actually constructed plants and technologies, they are characterized by an irreducible contingency.[5] Since nuclear reactions are not to any amount scalable down to laboratory experiments because of the involved critical masses of nuclear fuels, realistic test runs oftentimes can only be initiated in the already completed facility. The test case thus moves from a preparatory side to the actual and 'serious' operation of a facility.[6] As an effect, nuclear technology becomes a research area of "interactive complexity" and "tight coupling", as Charles Perrow notes in his classic *Normal Accidents. Living with High Risk Technologies*.[7] And this happens long before the field of Complexity Science starts to emerge in the 1980s. First and foremost, a highly complex facility like a LMFBR demands research and engineering strategies which cannot longer be

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[4] Häfele, "Hypotheticality," 53-54. The IIASA associate Philipp Pahner advances Thomas Kuhn's notion of a *paradigm shift* in order to describe the scientific culture of the Atomic Age. See Philipp D. Pahner, "Risk Assessment in the Nuclear Age," *IIASA Working Paper* WP-75-58: 1975: 3-4.

[5] Häfele, "Hypotheticality," 53.

[6] Olson McKinley e.g. describes unsuccessful test series with a 25-cm reactor model, see Olson McKinley, *Unacceptable Risk: The Nuclear Power Controversy* (New York: Bantam Books, 1976).

[7] Klaus Traube, "Vorwort," in *Normale Katastrophen. Die unvermeidbaren Risiken der Großtechnik,* ed. Charles Perrow (Frankfurt am Main/New York: Campus Verlag, 1987), xi.

elicited in the framework of traditional strategies of theorizing and experimentation – be it with regard to the regulation of physical chain reactions or the constructional realizations. Second, these technologies raise immense difficulties in estimating possible effects on the building materials and the environment. These become subject to projective risk assessments. And third, LMFBR technology only gains its status as a 'logical', desirable and economically feasible alternative energy source in the course and context of broader, also projective global energy consumption scenarios which are based on a specific set of underlying (and questionable) assumptions.[8]

No wonder that the systematic nescience which surrounds these potentially extremely dangerous technologies evoked severe criticism, with Häfele serving as a primary target. The Austrian author Robert Jungk picked him apart in a chapter of his anti-nuclear energy pamphlet *The Nuclear State*,[9] entitled "The Players". The section refers to those nuclear physicists who, at that time, proclaimed a lucent and clean new industrial age fuelled by the development of an immense future system of nuclear facilities.[10] Häfele served as their figurehead, not only as the doubt-relieved advocate of the German nuclear energy program, but also as a deputy director and head of the Energy Systems department at IIASA. This unique think tank was run as a joint-venture of initially twelve participating nations, including the USA and the USSR. Across the frontier of the Iron Curtain, IIASA's research groups developed global scenarios in the areas of population dynamics, environmental issues, nutrition, and energy markets.

In both fields, Häfele eagerly inseminated the novel epistemology which would hold for an operational handling of complexity, uncertainty and nescience – or, to use his neologism: for the domain of *hypotheticality*:

> Hypotheticality, of course, is not a word in the regular usage but its logic expresses precisely what must be expressed in the line of reasoning presented here. Its logic is the same as that of the word 'criticality', for example, a term which is familiar to reactor engineers. […A] reactor can become critical or a situation can be considered as hypothetical. The process of iteration between theory and experiment which leads to truth in its traditional sense is no longer possible. Such truth can no longer be fully experienced.

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[8] See Wolf Häfele, ed., *Energy in a Finite World. A Global Systems Analysis* (Cambridge: Ballinger Publishing Company, 1981).

[9] Robert Jungk, Der Atomstaat. Vom Fortschritt in die Unmenschlichkeit (München: Rowohlt, 1977), 41-69.

[10] Jungk, Der Atomstaat, 41-69.

> This means that arguments in the hypothetical domain necessarily and ultimately remain inconclusive.[11]

However, in order to generate an operational account for this "hypothetical domain", he called for novel media-technological procedures and modes of "abstraction".[12] These would help to execute the dynamical and processural effects in question, and would exceed the heuristics of theorizing and experimentation. Only techniques like scenario building, systems analysis (as prominently featured on all levels at the IIASA), and advanced computer simulations were capable to operationalize the problem contexts, possible security precautions, or estimates of future developments of the nuclear technologies in question. Without (analogue) techniques like scenario building and (digital) media technologies like computer simulations, the domain of hypotheticality would remain inaccessible for calculations of realistic threats and possible events. Häfele no longer connected 'knowledge' to 'truth'; in the domain of hypotheticality, 'knowledge' became a function of 'sufficiently accurate' calculations, statistical evaluations, and simulation results. In this context, CS provided an intermediate area, a differential space by generating 'virtual', dynamical test case scenarios which would prevent (catastrophic) eventualities in the 'real world'. As an effect, CS were devised to contribute to the elimination of the potentiality of such catastrophes to happen. In other words, and quite paradoxically, these media technologies were designed to hamper the realization of catastrophic outcomes of nuclear energy facilities *by realising* such occurrences in rather 'playful' ways inside their 'virtual' media environments.

Messy Systems

"[F]uture engineers may attempt the design of robots not only with a behavior, but also with a structure similar to that of a mammal. The ultimate model of a cat is of course another cat, whether it be born of still another cat or synthesized in a laboratory."[13] With this example, Norbert Wiener referred to the transforming apprehension and status of computer simulations after 1945. After World War II, computer technology provided the synthetic environment in which CS unfolded as "the process of representing a dynamic behavior of one system by the behavior of another system"[14] and gained their significance in current scientific cultures. Or,

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[11] Häfele, "Hypotheticality," 55.
[12] Häfele, "Hypotheticality," 63.
[13] Norbert Wiener, Arturo Rosenblueth and Julian Bigelow, "Behavior, Purpose and Teleology," *Philosophy of Science* 10 (1943): 18–24: 21.
[14] Michel Serres and Nayla Farouki, ed., *Thesaurus der Exakten Wissenschaften* (Frankfurt am Main: Zweitausendeins, 2004), 252.

to put it another way: A paradigm which Michael Gibbons once termed "Mode-1"-sciences – alluding to disciplines which were based on the experimental and mathematical mechanics of Newton – transformed into "Mode-2"-sciences whose non-linear problems had to be conceived of as a "behavioral science of systems".[15] Admittedly, Fast Breeders are not quite a sub-category of the abovementioned 'cats.' But as complex objects of inquiry they show a high degree of "interactive complexity" and "tight coupling". Charles Perrow described these instances as a sudden, unforeseeable concurrence of distant and independent system characteristics. In one of his diverse examples from nuclear reactor incidents, a simple faucet inside a reactor's containment structure which had not properly been closed by a cleaning brigade initiates a complex and non-linear succession of unlikely events of backflows and pressure modulations which finally resulted in a release of radioactive material into the structure. These interactions in the piping system, writes Perrow, were unforeseeable for the cleaning staff, as well as for the operators in the control room and the designers of the system. Only in an ex-post and step-by-step manner, the sequence of such hazardous incidents could be reconstructed.[16] And possible reciprocal effects of the manifold system elements can only be evaluated up to a certain degree:

> The more complex the system and the interactions between its components, the more likely is the occurrence of unexpected disturbances, the more ambivalent and thus misreadable are the signals which indicate the state of the disturbed system, and the more destabilizing instead of stabilizing can the reactions of operators or of automatic control systems become. The closer the individual components of the system (in terms of time, space, function) are coupled, the greater becomes the probability that local disturbances affect further elements of the system […].[17]

In the course of the development process of SNR-300 and his predecessors KNK-I and II, the interdependencies e.g. of nuclear fuels, cooling systems and building materials which cannot be sufficiently calculated by applying the classical theorems of theoretical physics, have been extensively discussed. In a 1977s expert roundtable on the SNR-300 project at the German Ministry for Research and En-

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[15] See Michael Gibbons, "The Emergence of a New Mode of Knowledge Production," in *Social Studies of Science in an International Perspective. Proceedings of a Workshop*, ed. Ulrike Felt and Helga Nowotny (Wien: Institut für Wissenschaftstheorie und Wissenschaftsforschung, 1994), 55-66. See Bernd Mahr, "Modellieren. Beobachtungen und Gedanken zur Geschichte des Modellbegriffs," in *Bild Schrift Zahl*, ed. Horst Bredekamp and Sybille Krämer (München: Wilhelm Fink Verlag, 2003), 59-86.

[16] See Perrow, *Normale Katastrophen*, 113.

[17] Traube, "Vorwort," xi.

ergy, Häfele states that "physicians […] generally underestimate how difficult it is from an engineering perspective to get even only one single reactor type going. [...] The physics is quickly done, but the engineering and the commercial implications are only to be accomplished with great expenditures of time and money."[18] However, the eerie thing is that these experiments – similar to the case of atomic bombs – have lasting effects on the real world since they are not contained within a laboratory setting. Furthermore, before their actual completion as a running reactor, the myriads of their components cannot be tested as a whole system.[19] This contradicts not only traditional engineering approaches such as the trial-and-error-based learning from past experience and the resulting step-by-step-improvement of a technical solution. It also unsettles the interplay of scientific hypotheses and experimental proofs. According to Häfele, contingency intervenes as the basic obstacle: "We can always improve our knowledge about contingent elements, but we can never make it complete. This restates the proposition that the residual risk can be made smaller than any given small number but it can never be reduced to zero."[20]

Nevertheless, the advocates of a bright nuclear energy future aimed at exploring the phenomena of interactive coupling as detailed as possible – with the help of the aforementioned 'behavioral science of systems'. Their narrative proposed the degrading of the system-immanent residual risks of a nuclear power plant to an insignificant level.[21] In the case of SNR-300, this predicament resulted in two distinct procedures: First, the enforcement of extensive physical large-scale component tests. These involved large numbers of interacting sub-systems and helped to reduce the amount of unforeseeable events and variables in the interactive coupling processes. The second procedure consisted of the application of systems analysis and computer simulation. These technologies enabled the engineers to build up an 'archive' of various computational scenarios of (hazardous) incidents and systems disturbances. In the case of a real accident, it would have been feasible to refer to one or more similar scenarios from the database, in order to initiate appropriate anticipatory actions to the developing effects of the accident. Such novel computer-generated scenario techniques outperformed the traditional pen-and-paper techniques known e.g. from cold war strategy planning in think

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[18] Hans Matthöfer, "Schnelle Brüter, pro und contra." (Protocol of a Hearing at the Federal Ministry for Research and Technology, Villingen-Schwenningen, Germany, May 19, 1977), 58. [Transl. SV].

[19] Jungk, *Der Atomstaat,* 48f.

[20] Jungk, Der Atomstaat, 53.

[21] See Lars Koch and Christer Petersen, "Störfall – Fluchtlinien einer Wissensfigur," *Störfälle. Zeitschrift für Kulturwissenschaften* Nr. 2 (2011), ed. Joseph Vogl, 7.

tanks like RAND.[22] Supported by computer technology, it became possible to calculate a multiplicity of cases. Following diagrammatical decision-tree structures, the researchers fathomed the eventualities and conditions of different courses of events in a narrative way. Henceforth, computer-assisted scenario building on the one hand fostered the comprehension of plurality, of decisive moments, of causality and non-linearity, and on the other promised to stagger the researchers with generating complexity even from restricted set of rules and involved factors. As an outcome, computational scenarios not only separated the heuristic coupling of trial and error, since the computer experimental trials only generated 'modelled errors', discharged possible hazardous effects, and thus conveyed trial and error-processes into the area of nuclear technology. Computational scenario building also coupled different trial-and-error elements – or IF/THEN-decisions – in decision trees.[23] Their diversified paths and results then became subject to evaluation processes according to a relational decision matrix. This made the definition of 'realistic', 'preferred' etc. cases possible. And more often than not, the 'extremata', the less probable and most deficient scenarios proved to hold the best heuristic value – a value which could be yielded without jeopardizing the environment by experimenting with hazardous nuclear technology.

Happenings

Apart from such computational scenario techniques, the Western German LMFBR project made use of large-scale component tests in order to merge detailed physical test series of interacting sub-components with comprehensive theoretical considerations about their interactive couplings. These then were projected onto the functioning of the completed future power plant. Or, as Häfele put it:

> For instance, the integrity of a pressure vessel is investigated as a sub-problem, and so is the operability of control rods and pumps. [...] In combining such components, more contingent elements come into the picture. The aim is to minimize the impact of incomplete knowledge of contingent elements. Therefore [...] the largest possible units are sought.[24]

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[22] See Thomas Brandstetter, Claus Pias and Sebastian Vehlken, "Think-Tank-Denken: Zur Epistemologie der Beratung," in *Think Tanks. Die Beratung der Gesellschaft* (Berlin, Zurich: Diaphanes, 2010), 17-58.

[23] See Wolf Häfele and Wolfgang Sassin, "Applications for Nuclear Power other than for Electricity Generation," *IIASA Working Paper RR-75-40* (1975), 33.

[24] Häfele, "Hypotheticality," 54

The tests were conducted in purpose-built experimental plants in Bensberg (FRG) and Hengelo (NL), where, for instance, steam turbines, cooling aggregates, detector systems against leakages, control panels, or the fluid dynamics of the cooling- and mediation circles were tested on a 1:1-scale.[25] Although, for financial and time-saving reasons, not all sub-systems of the SNR-300 would be tested in these experimental plants. Via cooperations with other international nuclear energy projects, SNR-300 profited from some of their findings, experiences and data. However, this implied questions about the transferability and adequacy of such data, since all these large-scale tests had been irrevocably limited to generate knowledge of only a restricted number of interactive couplings. Particularly, sensitive issues and hazardous scenarios remained in the area of theoretical reasoning and mathematical formalization – for example the diffusion of radioactive material into the atmosphere or the durability of shelter structures and containment measures. And quite ironically, some of the most reliable data which made its way into the mathematical modelling and assessment of the tests stemmed from past nuclear incidents.[26] Only to a very little extent, these sensitive issues could be approached by laboratory experiments due to their restricted scalability. As an effect, the *true* large-scale component 'test' in civil nuclear technology always implied the completed facility, and experimental reactors like KNK I and II served as indispensable precursors of SNR-300, which in itself was also conducted as only a preliminary stage for the development of a far larger future breeder, SNR-2. At the same time, the *true* large-scale *security* test is nothing else than the actual case of emergency, a case with an inherent, irreducible nescience: Or, as Häfele put it: "[...O]ne arrives at a situation where the truly large-scale test can only result in the statement that a given device functioned at a particular time and place. A general conclusion is impossible. [...O]ne may call such large-scale integral tests 'happenings'".[27] Not unlike a happening in the art world, this means that only those who were present are able to join in the conversation. And those who were not present know that the happening will not be repeatable in exactly the same way. Although, what gives the art aficionado a profit of distinction, only sets the scientist further back in the domain of hypotheticality. As an effect, in particular the branch which was concerned with disturbances in the interplay of various system components – later referred to as 'structural dynamics' – was

[25] See Willy Marth, *Der Schnelle Brüter SNR 300 im Auf und Ab seiner Geschichte*, (Karlsruhe: Kernforschungszentrum Karlsruhe GmbH, 1992), 54-62. See P. Ludwig and B. Hus, "Some Results of the 50MW Straight Tube Steam Generator Test in the TNO 50MW SCTF at Hengelo," *Summary Report. Study Group Meeting on Steam Generators for LMFBR* Bensberg (1974), 269-281.

[26] See e.g. D. D. Stepnewski et al., *Proceedings of the Fast Reactor Safety Meeting*, ed. ANS Technical Group for Nuclear Reactor Safety, Beverly Hills, CA (1974).

[27] Häfele, "Hypotheticality," 54.

delegated to computer simulation models from the late 1960s onwards.[28] The next two sections will discuss these various systems analysis and computer simulation techniques.

Systems Analysis and World Energy Models

The FRG's research in civil nuclear energy of the 1970s was to a good part devoted to a computer modelling discourse which at the latest gained world-wide attention by Dennis Meadows's *Limits to Growth* (1972) – systems analysis. It developed as a method from the Operational Research (OR) techniques of World War II. As an interdisciplinary approach, OR connected formerly separated military domains in a quantitative and qualitative optimization strategy and consulting format for strategic planning, with anti-submarine warfare as its seminal example.[29] Systems analysis pursued this approach mainly in the context of economic and 'socio-technical' problems after 1945. Coined by Edward W. Paxson at RAND Corporation, the term baptized a whole think tank with the foundation of IIASA in 1973. Leen Hordijk, a former director of IIASA, characterized the think tank's systems analysis philosophy retrospectively according to the following scheme – with computer simulation playing an outstanding role on all its stages:

> First, we marshal all the information and scientific knowledge available on the problem in question; if necessary, we gather new evidence and develop new knowledge. Second, we determine what the goals of the stakeholders are, both of the people and the institutions. Third, we explore different alternative ways of achieving those goals, and we design or invent new options, where appropriate. Fourth, we reconsider the problem in light of the knowledge accumulated. Fifth, we estimate the impacts of the various possible courses of action, taking into account the uncertain future and the organizational structures that are required to implement our proposals. Sixth, we compare the alternatives by making a detailed assessment of possible impacts and consequences. Seventh, we present the results of the study in a framework that facilitates choice by the stakeholders. Eighth, we provide follow-up assistance. Ninth, we evaluate the results. Please note that computer modeling

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[28] See Stepnewski et al., Proceedings of the Fast Reactor Safety Meeting, ix. See Wolf Häfele, Ferdinand Heller and Wolfgang Schikarski, The Principle of Double Containment and the Behavior of Aerosols in its Relation to the Safety of Reactors with a high Plutonium Inventory (Karlsruhe: Gesellschaft für Kernforschung M.B.H., 1967).

[29] See Claus Pias, *Computer Spiel Welten* (Zürich/Berlin: Diaphanes, 2002), 231-234, 244-249.

> is a useful device in helping obtain answers at any of the above stages.[30]

Scenaric *projections* – not *prognoses*, a distinction that already the authors of the *Report to the Club of Rome* underlined emphatically –, based on numerical computer simulations, become operative on two distinct levels: One the one hand, systems analysis was used to integrate Fast Breeder technology in world-wide energy production and consumption scenarios – with the department of Energy Systems at IIASA as an instructive example. On the other, it served as a technique for the concrete planning and assessment of the nuclear facility in Kalkar. Whilst Daniel Meadows's *Limits to Growth* – together with its underlying model of Jay W. Forrester's *World Dynamics* and its focus on "Resources", "Population", "Pollution", "Capital", und "Agriculture"[31] – only indirectly addressed the matter of energy supply, the scientists in Häfele's IIASA department explicitly centred around the latter.

In an attempt to anticipate the broad criticism that Meadows's demanding and far-reaching report was facing – for instance, its scenarios were perceived as mere toplofty computer games – the Energy Systems group was eager to emphasize that their scenarios only approached more concrete short- and mid-term projections, covering 15 to 30 years.[32] The individual studies of the group have been compiled to a sort of technical report, published under the title *Energy in a Finite World. A Global Systems Analysis* at the beginning of the 1980s.[33] The report was based upon a system of five simulation models which not only served as a 'projector' of two possible – and antagonistic – future 'energy worlds'. The models also synthesized a multiperspective analysis of attainable alternative energy sources and of technological developments with rather intuitive presumptions, for instance regarding the delivery rate of fossil fuels. Or, as the author of a commentary on the study put it: "The study makes use of scenario writing as a principal tool to investigate energy futures. These scenarios are not predictions, as the future is unpredictable; however, conducting studies such as these is necessary for responsibly dealing today with implications for tomorrow."[34] More concretely, the models can be differentiated along the following layout:

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[30] Leen Hordijk, "What is Systems Analysis?," in *Options Magazine* Winter 2007, accessed August 22, 2013, http://www.iiasa.ac.at/web/home/about/whatisiiasa/whatissystemsanalysis/what_is_systems_analysis.html.

[31] Donella H. Meadows et al., *The Limits to Growth* (New York: Universe, 1972), 89.

[32] See Paul S. Basile, "The IIASA Set of Energy Models: Its Design and Application," *IIASA Working Paper RR-80-31* (1980), 11.

[33] See Häfele, Energy in a Finite World.

[34] Basile, "IIASA Set of Energy Models", 2.

> The model set, long in development and following the initiative and guidance of Professor Wolf Häfele, includes several models: an accounting framework type energy demand model, a dynamic linear programming energy supply and conversion system model, an input-output model for calculating the impacts of alternative energy scenarios, a macroeconomic model, and an oil trade gaming model. The models have been designed into an integrated set for long-term, global analyses.[35]

This modelling strategy is significant for the research group precisely because it encompasses the possibility to generate a high level of interactive couplings, accounting for a far larger number of system parameters. One could state that the predicaments of data-driven science become prevalent decades before the contemporary discussions around big data technologies.[36] Already in the modelling process, it was crucial to assign to the output parameters an interpretable and not misleading amount of data in order to create novel *insights*. Further, this set of models produced instructive and reproducible *results*, because its basic logics were transparent and comprehensible. Such results, say the authors, could not replace but enhance careful reasoning. Moreover, computer simulations provided a *consistent environment* for the numerical calculation and classification of multiple, different scenarios. And last but not least, computer simulations enabled a self-critical and self-reflective *evaluation* of the results and the models by trial-and-error, as their formal structure could be 'validated' internally against comparative possible future scenarios, or externally against competing alternative simulation models.[37]

In these times of the *Limits to Growth* report, when the limitation of natural resources was perceived as the most pressing crisis for industrialized societies, the consideration of nuclear energy as a possible *solution* to societal needs instead of a *threat* to these societies becomes more reasonable. Thus, it is not a coincidence that Fast Breeders played a significant role in the nonchalantly devised future energy supply scenarios at IIASA: Calculating with an at least linear increase in world-wide energy demands, according to one scenario, a system of 3000 LMFBRs and High Temperature Reactors (with an output of 3300 MW per unit), combined with 650 temporary and 47 terminal nuclear waste repositories and various facilities for the production of chemicals and fuels (like hydrogen), would

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[35] Basile, "IIASA Set of Energy Models", 2.

[36] See Joachim Müller-Jung, "Wird 'Big Data' zur Chiffre für den digitalen GAU?," *Frankfurter Allgemeine Zeitung*, March 04, 2013, accessed May 02, 2014, http://www.faz.net/aktuell/wissen/mensch-gene/bioforschung-an-grenzen-wird-big-data-zur-chiffre-fuer-den-digitalen-gau-12103088.html.

[37] See Basile, "IIASA Set of Energy Models," 4.

easily provide the world of 2030 with energy and useful by-products, manufactured by using the process heat of the plants. This, state the authors, would be realizable by an almost closed nuclear fuel cycle, demanding only 8500 tons of uranium or thorium. In comparison, a coal-based energy production would amount to a requirement of 18,3 billion tons.[38] And also solar energy is comparatively considered: However, if designed to meet the projected future energy needs, the area to be covered by solar panels would amount to "about 20 times the area of Germany"[39] – hardly a viable and environmentally sustainable way, the IIASA report asserts.

If one realizes how such encompassing CS made possible a quantified comparison of apples and oranges in the same computational framework, it becomes more understandable how someone would have developed the idea of constructing a 'messy' technology as a Fast Breeder in the first place: The dangers of any possible energy source are situated on the very same level and in a common matrix. As a part of a system of computer simulations, they become objects of the same media-technological condition of trial-and-error procedures which facilitate an 'adequate' and comparative assessment of their respective 'dangerous' potentials. It is only this combined quantification of data and its transformation into qualitative computational scenarios which let projects like the SNR-300 appear as reasonable options.

Alas, what on first sight would sound like a complete success story of a bright nuclear future becomes critical at the latest when more complex systems and more uncertainties of the real world break into the modelling logics of the involved systems analysis techniques. Take as an example that IIASA and the IAEA would only in hindsight realize certain apparent flaws in their reasoning: "Yet, together with the [...] IAEA an effort was made to understand the discrepancy between the 'objective' risks of nuclear power and its perception by the public."[40] Since the scenarios of the Energy Systems group and thus the projected outcomes and implications always rested upon speculative registers and were played out in the field of hypotheticality, they themselves became objects of competing (and far less optimistic) counter-scenarios. These counter-scenarios thematise for instance the fact that Fast Breeders produce not only nuclear fuels for other conventional reactor types, but also large amounts of weapons-grade plutonium – and besides, also of highly radiant plutonium waste. Not only for fervid critics of the breeder technology like Robert Jungk, this perverted the proclaimed image of a clean and peaceful Atomic Age into an uncontrollable 'plutonium-

[38] See Wolf Häfele, "The Comparison of Energy Options – A Methodological Study," *IIASA Status Report SR-80-2* (1980), 94.
[39] Häfele, "Hypotheticality," 57.
[40] Häfele, "The Comparison of Energy Options," 96.

based economy' and utterly doomed 'plutonium world'.[41] As a matter of fact, and due to the concentration of critical amounts of plutonium in its cores, fast breeders – unlike traditional reactors – not only run the risk of a nuclear meltdown, but also of a nuclear explosion. And even their location in sparsely populated and structurally backward regions would hardly account for this circumstance. Some ten years after the publication of the IIASA studies, discrepancies like these and an ever more accelerating anti-nuclear protest culture would not only bring computer-modelled plutonium worlds of a future FRG to the fall, but also its landmark and first concrete step into such a future: SNR-300.

Designing Hypothetical Nuclear Power Plants

Albeit, before its final decline in 1991, SNR-300 first had to surge – at least up to a certain point. And this concrete technical advancement had partly been based on systems analysis and computer simulations. The involved software applications more often than not were labelled with quite adventurous acronyms – until today, the invention of hilarious wordplays seems to remain an inextinguishable hobby of computer scientists, worth a separate paper. Already developed in the course of the KNK preliminary breeder projects, the software *MUNDO* (for MaximaleUNfallDOsis, translating to 'maximum accidental dose') simulated the diffusion of radioactive particles in the atmosphere after a hazardous incident. Its application, for instance, proved the essential benefit of double containment structures for reactor cores. These enabled filter- and disintegration processes of leaked radioactive material inside a second insulation structure. MUNDO calculated such internal processes along with the possible reduction of danger for atmospheric contamination outside of the facility. It leads to an active protection procedure which was highly relevant for plutonium-fuelled breeders, and which played a decisive role in the administrative approval in the early stage of the SNR-300 project. Complementary, and under the impact of the partial meltdown of the *Fermi-I* experimental breeder in Newport, MI, not far from Detroit, a team in the US developed the encompassing security software – nomen est omen – *MELT-III*. It nu-

[41] See Roland Kollert and Inge Schmitz-Feuerhake, "Die Plutoniumopfer eines ausgebauten Brütersystems. Versuch einer Abschätzung," in *Die Gefahren der Plutoniumwirtschaft*, ed. Günter Altner and Inge Schmitz-Feuerhake (Frankfurt am Main: Fischer, 1979), 43. H. Bonka et al., "Zukünftige radioaktive Umweltbelastung in der Bundesrepublik Deutschland durch Radionukleide aus kerntechnischen Anlagen im Normalbetrieb," *Berichte der Kernforschungsanlage Jülich* Nr. 1220 (1975).

merically modelled a variety of possible thermal and hydraulic reactions in the course of a nuclear meltdown.[42]

Other software tools simulated diverse operations in the abovementioned field of structural dynamics. These encompassed, among others, steam explosions, interaction between natrium cooling cycles and reactor fuels, the deformation of fuel rods by pressure variation in the cooling agents, heat exchangers,[43] the shielding capacity of different materials, the calculation of neutron collisions, or models of turbines.[44] Add to that the digital "scale model tests" of complete breeder facilities.[45] All these applications had one thing in common: They modelled processes whose exploration under a traditional paradigm of experimentation would have been too dangerous or plainly impossible. Although, this did not at all imply that the models would converge to *one* feasible and realistic procedure in the course of their iterated trial-and-error runs. Rather, they generated a comparability of multiple hypothetical cases and served as an advisory, as tools for thought for the apprehension of promising actions and constructional implementations.

But even in this regard, the computer programs were subject to multiple limitations. First and foremost, the development of the program codes was dependent on the "availability of effective calculating machines".[46] During the SNR-300 project, for instance, the "flow distribution of neutrons in the beginning could only be resolved in a one-dimensional diffusion approximation". Not before the acquisition of faster computer hardware, "one turned [...] to a two- and three-dimensional treatment."[47] Second, the latencies of software systems oftentimes

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[42] See Ferdinand Heller, Wolfgang Schikarski and A. Wickenhäuser, "MUNDO – Digital Programm zur Berechnung von Unfalldosen in der Umgebung einer Reaktoranlage," *KFK*-653 (1967). See Wolf Häfele, Ferdinand Heller and Wolfgang Schikarski, "The Principle of Double Containment and the Behaviour of Aerosols in the Relation to the Safety of Reactors with a High Plutonium Inventory," *KFK*-669 (1967). See Johan F. van de Vate, "The Safety of the SNR-300 and the Aerosol Model; A Summary Report of the RCN Aerosol Research 1967-1971" *Working Paper RCN-174* (1972). See Alan E. Waltar et al., "Melt-III. A Neutronics, Thermal-Hydraulics Computer Program for Fast Reactor Safety Analysis, Volume I," *Hanford Engineering Development Laboratory Working Paper HEDL-TME 74-47 UC-79p, e, d, b*, (1974).

[43] See Stepnewski, Proceedings of the Fast Reactor Safety Meeting, 679-784.

[44] See Robert Avery, "Reactor Computation Methods and Theory," in *Applied Physics Division Annual Report* 1971, 367-456.

[45] See Stepnewski, *Proceedings of the Fast Reactor Safety Meeting*, 679-700. David Saphier, "A Dynamic Simulator for Nuclear Power Plants (DSNP)," *Argonne National Laboratory Memorandum ANL-CT-76-23* (1976).

[46] See Marth, *Der Schnelle Brüter SNR*, 53. (Transl. SV)

[47] See Marth, *Der Schnelle Brüter SNR*, 53. (Transl. SV)

inhibited the exploitation of already available computing resources. As late as 1973, more than 10 years into the "German Manhattan Project", the flexible and modular software system *KAPROS* replaced an apparently painstaking predecessor. *KAPROS* integrated, among others, the program suites *REX* and *FAUN-Z*, developed by the SNR-300 project group to explore so-called *Bethe-Tait Worst Case Scenarios*,[48] analogous to the US-American *MELT-III* software. The stage before the disintegration of a reactor was simulated by the software *CAPRI-I*, whose calculations relied on data input and model characteristics of sub-programs like the fuel rod simulation module *BREDA* or – and here again the acronym reads thoroughly self-deprecating – the boiling module *BLOW 3*. The simulation of the actual phase of disintegration and stress tests of the containment structures again involved further software applications[49] Hence, and despite such efforts in terms of modularizing the software, different processes continued to be modelled by a variety of specialized, independent CS programs. The respective white papers give little insight regarding their respective integrativity. It remains disputable whether these computer programs had been integrated to a similar extend as those of the IIASA energy studies and if they, as a result, provided a comparable analytic framework.

And finally, the mentioned programming and simulation efforts attached to a fundamental problem: How appropriate would their codes represent the real-world processes in question? In this regard, mathematician Keith Miller of Berkeley University publicly criticized the codes which were used in the US to generate scenarios of nuclear incidents. In Walter Cronkite's CBS news show on May 12, 1976, he stated that these were "totally inadequate to the complexity of the problem [..., and therefore] just as reliable as tomorrow's prediction of the weather, and I wouldn't trust my life on tomorrow's prediction of the weather."[50] To underline his statement, Miller elucidated the work flows of the respective code development processes. Some working groups dealt with "advanced codes" for future software versions. Other teams checked the correspondence of these codes to real-life-phenomena by verification studies. And further groups calculated the actually ongoing construction processes with antecedent – and therefore, already outdated – program versions. The mathematician furthermore added three observations: First, the codes used for calculating the construction processes oftentimes would not correspond with those employed for the evaluation of, for example,

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[48] Hans Bethe and J.H. Tait, "An Estimate of the Order of Magnitude of the Vigorous Interaction Expected Should the Core of a Fast Reactor Collapse," *UKAEA RHM* (56)/113 (1956).

[49] Marth, Der Schnelle Brüter SNR, 55-56.

[50] Philip M. Boffey, "Nuclear Safety: A Federal Adviser's Warnings Provoke Ire of Colleagues," *Science* 192 (1976), 978.

security measures. Second, the margins which defined the possible scope of identifying problematic incidents were set too narrow. And third, Miller demanded the application of a larger number of large-scale simulations. Even in the 'virtual', he stated, due to limited computing capacities, more often than not only sub-components and sub-systems were tested, and the risk potential of the large-scale system thus would only be extrapolated from these tests.[51]

Although, Miller's last argument was itself countered by another categorical remark: According to Richard T. Lahey, one of the leading nuclear experts of the US in the 1970s, the simulation of large-scale systems was "absolutely the worst test to run to get data". For the not even remotely comprehensible multiplicity of involved variables and factor combinations would inhibit the necessary, detailed identification and reconstruction of critical disturbances.[52] Analogue to the IIASA energy studies, the engineering simulations of actual nuclear facility constructions were also facing a tremendous big data-problem.

Making History, Changing Futures

A media history of nuclear technology in the 1970s, with Fast Breeder programs as its epitome, reveals some of the essential elements of an epistemology of computer simulation. As systematic approaches to conquer new fields of knowledge, CS developed into ground-breaking technologies in big science projects – especially in research fields with a high amount of hypotheticality. The complexity and criticality of nuclear technology seemed predestined for their application, be it in a broad framework of socio-economic systems analysis studies, or in the concrete case of a system of – more or less integrated – engineering simulations.

However, and despite the appliance of CS in construction and technological impact assessment, quite large problem areas remained a field for speculation: Fast Breeders came into existence as "happenings', they literally 'took place', be it inside of simulation scenarios or outside in the 'real world'. Such forms of happenings could only be flanked by passive or active security measures built in the physical constructions. But as we have seen, these are often themselves based on questionable codes and scenarios.

All these measures contain a structural residual risk larger than zero. How large exactly this residual risk was allowed to be was the subject of negotiation processes between technological, economical, and political factors and agents. These negotiations ultimately defined what was meant by 'safety', and which criteria would qualify 'safe' as *safe*. For advocates of the atomic age like Wolf

[51] Boffey, "Nuclear Safety," 978.
[52] Boffey, "Nuclear Safety," 979.

Häfele, the benefits of nuclear energy always clearly outnumbered their dangers. All other critical reservations were considered as inappropriate interpretations in the age of hypotheticality. And in the case of doubt, at least Häfele preferred to lead a wild and dangerous life in view of the potentials of the atom.[53]

The afterlife of this systematic appliance of computer simulations in critical environments and its effects on our contemporary situation on the one hand becomes obvious in the discourse of climate change. Not coincidentally, some scientists claimed a necessary world-wide 'renaissance of nuclear energy'.[54] On the other hand, the afterlife functions on a more fundamental level, driven by the temporal logics of these novel media technologies: CS *generate* a variety of possible futures and rationalities, and at the same time *describe* and *operationalize* them. Culminations like *residual risk, worst case scenario, climate catastrophe, peak oil* or the telling Cold War acronym *MAD* (for Mutual Assured Destruction) emerge precisely in those media-historical situations when computer simulations made feasible a *Thinking About the Unthinkable*[55] (Herman Kahn): by distinguishing between multiple projective scenarios, and by providing the conditions to evaluate and choose the most and least desirable futures. Moreover, CS delineate solution strategies for exactly the crises and catastrophes that only could have been formulated under their media-technological condition. CS thus gain their significance to a lesser extend in correspondence to 'real' events, but rather to the *prevention* of such events. Today, as ever more sophisticated CS model the behaviors and futures of complex systems across almost all scientific disciplines, they ever more impose a particular understanding of the world: Due to its future-orientation (and media-technological 'future-adjustability'), this world can only conceive of itself in terms of perpetual crises. Every present time now is faced with the haut gôut of deficiency, because it is permanently confronted with a multiplicity of futures. These are presently 'happening' as media-technological operationalizations, and thus force their technological principles of optimization, efficiency, and stability upon that very present time.

But at least in the 1970s, such a far-reaching age of hypotheticality remained utterly uncontrollable. And the media history of SNR-300 gives an impressive disclosure of this fact: Even the avantgarde of hypothetical scientific research and its media technologies proved incapable for dealing with the socio-economic dynamics of the emerging anti-nuclear movement in the FRG – a

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[53] See Jungk, *Der Atomstaat,* 49.

[54] See e.g. William C Sailor et al., "A Nuclear Solution to Climate Change?," *Science* 19 (2000), 1177-1178. J. Pacala and R. Socolow, "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies," *Science* 305 (2004), 968-971. John Deutch et al., *The Future of Nuclear Power* (Boston: MIT, 2003), 1-13.

[55] Herman Kahn, Thinking about the Unthinkable (New York: Horizon, 1962).

movement which organized and radicalized itself precisely around megalomaniac nuclear projects like the Fast Breeder. Finally, the epistemology of hypotheticality was ultimately challenged as something actually *happened* in the 'happenings': The incidents of Three Miles Island (USA, 1979), and even more profoundly of Chernobyl (USSR, 1986) messed up all the former scenarios. In the face of these incidents, a normative power of the factual overwrote the variables of the "venturous speculative research styles"[56] of CS. This 'factual reality' generated – at least in the FRG and for the SNR-300 project – novel contingencies with ever more influential socio-political and ecological variables. And these underestimated 'risks' could not be reduced to a viable level by CS – there was no scenario for nuclear phaseout in the database of the "archpriests of the Atomic Age."[57]

After the anti-nuclear movement had opted against nuclear hypotheticalities and had brought the German Manhattan Project to the fall, alternative future scenarios came into being, sometimes even turning away from the doctrines of economic growth and technological progress. IIASA switched to the research of more sustainable energy sources and 'green technologies' in the post-Häfele era, eliminating Fast Breeders from the scenarios already in the mid-1980s. And at the beginning of the 1990s, after never having become equipped with radioactive material, let alone having become critical, the liquid natrium cooling cycles of SNR-300 – which had been desolately run for six years – were switched off, and the Breeder was shut down. From that moment on, the future of SNR-300 took shape as the utmost improbable and extremely hypothetical afterlife as an amusement park. But what remained undisturbed by this decline was the ever increasing relevance of computer simulations as media technologies and cultural techniques[58] which continue to set up or present futures and future present.

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[56] Jungk, Der Atomstaat, 50.

[57] Manfred Kriener, "Im nuklearen Fieberwahn", *Greenpeace Magazine* 2 (2005), accessed August 22, 2014, http://www.greenpeace-magazin.de/magazin/archiv/2-05/atom-50er-jahre/

[58] See Sebastian Vehlken, "Zootechnologies. 'Swarming' as a Cultural Technique," *Theory, Culture and* Society 30 (2012), (Special issue *Cultural Techniques*, ed. Geoffrey Winthrop-Young, Jussi Parikka and Ilinca Irascu), 10-131.

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