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Nuclear science and technology in the Malaysian context: Three phases of technoscientific knowledge transfer (ETTLG)

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ABSTRACT

This essay considers the development of the nuclear science programme in Malaysia from a transnational perspective by examining the interactions between state agents and other external nuclear-knowledge/technology related actors and agents. Going beyond the model of knowledge diffusion that brings together concerns articulated in Harris's (2011) geographies of long distance knowledge and Reinhardt's (2011) role of the expert in knowledge transfer, the proposed three-phase model of knowledge transfer theorises the pathways undertaken by a late-blooming participant of modern science and technology as the latter moves from epistemic dependency to increasing independence despite the hurdles encountered, and the underdevelopment of many areas of its technoscientific economy. The model considers tensions stemming from the pressures of expediency for meeting national developmental goals on the one side, and the call to support the objectives of basic science on the other. The three phases of the model are epistemic transition, epistemic transplantation and localisation, and epistemic generation (ETTLG). As additional support for the proposed model, three arguments are proffered as deeper explanations of the epistemic goal by using Malaysia as a case study: knowledge transfer for political legitimization, knowledge transfer for countering agnotology, and knowledge transfer for social engineering and science diplomacy.

1. Introduction

In the philosophy of science, there are discussions on knowledge transfer as a form of epistemic translation between science-theoretical abstract models and closed-system physical/simulated systems (Humphreys and Imbert (eds.), 2012; Morrison, 2015; Weisberg, 2013). However, there is not yet a knowledge transfer model describing the knowledge transfer of open-ended complex systems at a social-epistemological level, such as that of knowledge transfer involving polycentres of technoscientific actions spread over a longue durée of space and time. The attribution of longue durée is justified in terms of the recurrence of recognizable epistemic patterns even with the translation of that knowledge over rapidly evolving epistemic or non-epistemic circumstances (Grote, 2015). The specification of the longue durée is applicable to knowledge societies that have undergone periods of disruptions to, and ruptures in, their traditions of knowledge, usually because of colonialism, thereby resulting in truncated timelines for the development of intellectual events that would otherwise have had more time to take root and evolve over a timespan longer than a mere matter of decades.

At present, most discussions of macroscopic and complex forms of knowledge transfer in R&D (research and development), innovation, and science and technology studies are taken up, mainly, in management, policy, geographical, economics, and sociological studies (Böcher & Krott, 2016; Howlett (ed.), 2011; Lin, 2000; Nilsen & Anelli, 2016). Moreover, in knowledge transfer systems that consider the relationship between developed and developing nations, the focus has always been on inter-firm or inter-organizational (commercial or otherwise) forms of co-operations (Goel & Rustagi, 2006; Narteh, 2008). A knowledge transfer model that takes into account open systems operating across vast timescales, as well as epistemic, social and geopolitical inequality, is needed for a systematic and critical accounting of the historical and sociological development of knowledge systems such as that represented by the Malaysian nuclear science and technology programme discussed here.

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Porous and ever-shifting political, economic, and epistemic boundaries inform the development of Malaysia's nuclear science and technology programme. These boundaries are illustrated in Harris's (2011) three concepts of knowledge geographies. The first concept concerns static knowledge. In Malaysia's nuclear case, static knowledge pertains to agricultural and industrial needs, hydrology, medical infrastructures, and the measurement of radioactive fallouts. The second concept governs "kinematic geography of movement," which is represented by the transfer of resources (from grants-in-aid to books and training manuals), 'portable' experts (Mehos & Moon, 2011), instrumentation (research reactors and irradiating instruments), and standards for building research programmes. The third instance is represented by the "dynamics of travel" involving technical attachments to laboratories, research institutions or universities abroad; the periodic visits of experts sent via the International Atomic Energy Agency (IAEA), submissions by Malaysia-based scientists to IAEA's online repository INIS; and presentations of technical progress at meetings.

However, the transfer of expertise between donor and recipient produces inequity because the knowledge remains coupled to the primary expert, and requires the latter's continuous management. Reinhardt (2011) discusses knowledge transfers from the perspective of service, training and collaboration; service involves the transfers of knowledge and information from entities producing that knowledge to external clients, training focuses on the expert training of peer scientists or technicians, while collaborations involve the establishment of mutual benefits, usually among actors located in different industries, but with a shared interest in deploying specific techniques or expertise.

While the framing of knowledge diffusion/circulation by Harris and Reinhardt are both applicable to the case considered here, the perspectives offered are only partial because neither of the frameworks could sufficiently explain how nuclear knowledge transfer contributed to instantiating the scientific values and practices of an emergent nation, nor how a recipient nation such as Malaysia, having entered late into scientific modernity, could catch up without sacrificing their intellectual independence while reclaiming epistemic agency in the process.[1]

The model of knowledge transfer that will be proposed is not concerned with the direct benefits of knowledge diffusion between parties and how to accrue these advantages. Rather, the model intends to address the transitional phases that influence and impact the epistemic attitudes of a state actor or institutional entity when the latter evaluates and re-evaluates its science and technology policies and knowledge process in relation to its identity and position within a global technoscientific exchange. Moreover, science and technology in service of bread-and-butter issues and the public good (Gwynne, 2011) or public interest (Carrier, 2011) will affect how science attains social legitimation and authority in developing nations such as Malaysia. Carrier points to two worries associated with the politicisation and commercialization of the scientific enterprise: the selection and establishment of a research agenda, and the testing and confirmation procedures of science. He is concerned with how short-term agendas driven by politics and commerce, rather than honest inquiry, could turn morally and epistemically repugnant.

In addition, the seeming preference for applications-based or development-driven research by developing nations was encouraged by the same developed nation waxing lyrical over the importance of basic research, as emphasis was put on transferring knowledge considered as fulfilling developmental goals rather than driving foundational inquiries (de Greiff & Olarte, 2006). The 'imported' science did not come pre-packaged with easily transferable scientific traditions; and the pressures of catching up in the age of globalization are greater than the ability to maintain a disinterested stance when funding is precarious and the timely production of results is required for the research to receive continuing support. One such compromise that Malaysia has to make is encapsulated in Carrier's suggestion that doing research in the context of science application does not diminish the epistemic quality of the science; what is required is the instituting of checks for maintaining accountability.[2]

Therefore, this article advances a model of knowledge transfer that represents how a still economically developing state actor, which is Malaysia in this case, could move from epistemic dependence to increasing independence in the production of technoscientific knowledge. Such a model is only applicable to epistemic state actors that have arisen as a result of 1) postcolonial reorganisation 2) enculturation of different epistemic systems, even if the state actor had neither undergone geographical reconfigurations nor been a recipient of colonial interventions, stemming from major epistemological (and intellectual) shifts as an outcome of the modernisation project.[3]

The generalizability of a model at a macro level does not preclude micro-level adjustments to fit the different narratives of entities sharing intersecting characteristics. Moreover, outright generalizability becomes difficult when one has to attend to a plurality of contextual circumstances evoked by a single concept. For instance, doing research in the context of application could just as much mean, within certain social contexts, the integration of native/indigenous knowledge with modern 'western' science in scientific research, as much as imply, a privileging of applied science over pure science or curiosity-driven research.

The most proximate knowledge transfer model (from a science policy perspective) that takes on a three-tier/three-phase structure is the RIU (Research, Integration, Utilization) model, referenced above (Böcher & Krott, 2016), that considers how science and policy stakeholders could interact, and what both sides could do to optimise and maximise communication and understanding to ensure the successful transfer of science and technological knowledge to political actors with the most power to deploy that knowledge towards public good. However, the model is limited to an examination of closed systems (such as knowledge transfers taking place among entities within the same nation state). Further, the model focuses on the pragmatic motivation behind knowledge transfer of states that are already scientifically well heeled, in contradistinction to the proposed model's intent at unpacking conditions that drive the pragmatic and utilitarian impetus of states that are still catching up scientifically, or lacking in scientific pedigree and capital.

Therefore, the proposed model, abbreviated to ETTLG: epistemic transition, epistemic transplantation and localisation, as well as epistemic generation, extends beyond the RIU model by scaling up the multiple forms of knowledge transfer between different categories of allies across international (and transnational) political and technoscientific timelines. These allies could be internal to the sciences (whether within the same or different scientific disciplines) or external agents (involving interactions between

[1] I will not enter into a discussion concerning the position and interaction of indigenous or local scientific knowledge forms with 'imported' western science.

[2] There are important philosophical issues pertinent to the topic of applied vis-à-vis pure science distinction that could be considered within the development of Malaysia's nuclear science and technology programme, but that is another topic best discussed in a different essay.

[3] Modernisation is used in a general sense here, and not for characterising a specific cultural period.

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international agencies and state actors, different state actors, as well as individual communities and entities in governments).

The first phase, epistemic transition, began from the late 1950s until 1970; this phase was characterised by pre-industrial modernity and postcolonial reforms as Malaya (before it became Malaysia in 1963) wrested back control of a newly reconstituted state (previously made up of different Malay kingdoms); the nation went from epistemic exclusion to gradual inclusion through increasing epistemic autonomy and international political recognition. This period coincided with a global campaign for the non-proliferation of nuclear weapons (of which Malaya was actively involved via the United Nations), the establishment of the Atoms for Peace program and the International Atomic Energy Agency (IAEA), as well as international expansionism through developmental aids and technical assistance. Technological infrastructures underwent consolidation for national development, and socio-economic collaborations were formed with the establishment of the Association of Southeast Asian Nations (ASEAN). The end of this phase was signalled by Malaysia joining the IAEA as a member state (Member States | International Atomic Energy Agency, n.d.), marking the start of its involvement in developing nuclear knowledge.

The second phase, epistemic transplantation and localisation, which developed from the 1970s until the late 1980s, represented knowledge transfer as a two-prong process: the transmission of blackboxed nuclear technological knowledge and other generic scientific knowledge through technical assistance and gifts-*as*-aids (in the form of books, journals, technical manuals, etc.) intended for local infrastructural and capacity building. The transmission of blackboxed knowledge, which is knowledge transmitted from donor to recipient without the latter having access to the mechanism that produced said knowledge, was through 'approved' technical information. In terms of nuclear technology, much of the knowledge transferred in the 1970s, and the first part of 1980s, could be conceived as operational knowledge since facilities for experimental research were not available until the early 1980s. Further, the transmission of nuclear technologies was proportional to the rate of economic development of the still industrializing states.

Nevertheless, these low level technological transfers were complemented by basic science research taking place in Malaysian campuses across the physical and life sciences; there were small-scale ventures into fundamental nuclear physics research by the early 1980s. Capacity building involved producing caches of local scientists with PhDs through the Malaysian government scholarships and Colombo plan.[4] Technical assistance came not only from more developed countries but also from neighbouring ASEAN countries, such as Indonesia, who was one of the earliest adopters of nuclear technology in the region. A national agency was established to facilitate technology transfer at the level of intergovernmental agencies, with assistance from the IAEA.

The third phase, from the late 1980s until the present time, is a period when extant intellectual capital of the state is maintained while preparations are made towards the attainment of greater self-sufficiency. I refer to this phase as epistemic generation, although reliance on expertise for higher-order scientific knowledge transfer continues. This phase has increased peer-level bilateral collaborations (instead of unilateral transfers from more scientifically and technologically advanced donor states) between Malaysian and overseas scientific institutions; this is done by building up knowledge that draws on the affordances provided by the local landscape, and through the manufacturing of their own equipment for R&D. The national nuclear agency continues to mediate the transfer of nuclear technologies to industry. Projects with immediate practical utility are often preferred over riskier ones.

After decades of being non-committal, 2016 became the year when the Malaysian government was making serious efforts towards the appropriation of nuclear power; its nuclear power infrastructure development had already been assessed by the IAEA at the time of writing (Chatzis, 2016; Liew, 2016). How Malaysia might be a strategic and important polycentre of applied nuclear research remains to be seen, as are its attempts at contributing to epistemic generation. Moreover, there is need for further contemplation over whether Malaysia would continue with a mode-2 research programme driven by science in the applied context, although one could argue that the distinction from basic or mode-1 research is superficial (Nordmann, Radder, & Schiemann, 2011). The Institute of Physics Symposium in 1976, and the first Asia-Pacific Physics Conference in 1983 (Arima et al., 1984), both held in Singapore, saw Malaysian physicists presenting on their work in theoretical and basic science research in both nuclear and particle physics, regardless of the national emphasis on science for development (Alvares & Sachs, 2010, pp. 245–247; 250–252).

However, it must be noted that the three phases could not be parcelled out into neat timelines; overlaps are inevitable. The longue durée of Malaysian nuclear science and technological development is characterised by recurrent aspects of earlier phases within the later phases of its development since a transition requires one to revisit accumulated legacies prior to deciding on the next move. The development of the nuclear programme is an outcome of the evolution of Southeast Asia's nuclear technoscientific polycentres that have emerged out of several contingencies: the 'superpowers' desire to form alliances with, and gain political support from, emerging nations; anxiety over the future of energy resources to meet demands of national progress; as well as political survival and security. The transfer of nuclear technology for non-proliferation purposes into Southeast Asia forms the earliest instance of a large-scale technoscientific knowledge transfer from more developed states (of the North) to emerging and developing nation states (of the South) following the Second World War; such knowledge flows form the first recognizable instance of technoscientific diplomacy that configures the history of nuclear science and technology as one that is ultimately transnational and international. Therefore, technoscience in this case signifies the coupling between science as the knowledge source and technology as the harnessing of that knowledge for socio-technical engineering. The next section offers up three arguments on the rationale behind the technoscientific knowledge transfer discussed.

2. Rationalizing technoscientific knowledge transfer

The ethics of prioritarianism in pursuit of development and distributive justice informs the sensibilities of the national technocratic regime desiring the flow of technoscientific knowledge from what seems to be epistemically richer centres to the periphery. The pursuit of such knowledge transfer is underpinned by a need for political legitimization, countering agnotology (ignorance), and social engineering through science and technology diplomacy. These arguments inform the postcolonial imperatives for uplifting the morals, spirits, and intellect of a nation depleted of dignity from long-term imperialism.[5] The first and third arguments

[4] Information for this had been obtained from interviews with scientists who were recipient of scholarships under one of the plans, as well as from the records provided by the Rockefeller Archives Centre. See Ford Foundation, 1962–1964.

[5] While there were publications that came from the nationalist movements and colonial social uplift societies, I will not address them here.

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had shown up in various guises within area studies, international and global studies, political science, sociology, economics, and the historical studies of Malaysia, while the second argument is given scant attention. Even as there exists state imposed agnogenesis, the focus here will be on the strategies the state deploys to combat agnotology in the fulfilment of its technocratic goals.

Knowledge transfer as political legitimation is a necessary move by an incumbent government seeking legitimation by publicising its attempts at improving the social and economic levels and statuses of its citizens, especially segments of citizens that make up the backbone of the incumbent's political support. In Malaysia's case, political legitimation is crucial for countering criticisms concerning how the incumbent rose to power as a result of a bargain struck between the outgoing British administrators and their approved Malayan political parties in order to maintain British interest (White, 2004); therefore, the incumbent's best way of attaining legitimation is by ameliorating scarcity and deprivation. As higher-level science and technology training ramped up from the late 1950s, a technocratic state was born out of a need to manage infrastructures and commodities and develop labour capability, with strategies as outlined in the First Malaysian Plan of 1966–1970. By 1970, the technocratic mission has become firmly established, with a single line from the National Principles of Malaysia declaring the state's unequivocal goal in "building a progressive society which shall be oriented to modern science and technology" (Rukunegara, 1970; Rukun Negara: guiding or forgotten principles, 2004).

The technocrat[6] could be elucidated through a triangulation between society (the public), government, media, and scientists within the configurations of science, technological innovation, and ethical discourse (Bucchi, 2009). In the case of Malaysia, the formation of the technocrat could be historicized by locating its genesis at the intersection of its colonial intellectual heritage (and introduction to modern western technoscience) and a postcolonial appropriation of that heritage in the service of nation building. Moreover, the simultaneous development of a national scientific council and industry action plan in the 1970s produced strategies for creating linkages between basic/laboratory sciences of the public universities and industry, although this does not often translate well in practice due to the amount of legitimacy, jurisdiction, and control government agents have over the other sectors. Nevertheless, the innovation strategies, the distribution of seed funding, and political interests in developing particular communities of entrepreneurs by the Malaysian technocratic leadership between the 1970s and the 1990s (Felker & Jomo, 1999) enabled the national nuclear science and technology agenda to work hand in glove with its industrialization project.

Knowledge transfer for countering agnotology[7] could be considered through two instances.[8] The first instance relates to breaking a culture of ignorance stemming either from the failure of a knowledge type to penetrate a community, or from intentional deprivation/filtering out of said knowledge; in either case, an epistemic deficit requires rectification through long-term training programmes to reduce reliance on external expertise and to encourage knowledge generation by local knowledge/scientific communities. However, the encouragement of one form of knowledge does not translate into an overall resolution of ignorance, as the state is most interested in targeting knowledge areas that could contribute most immediately to fulfilling its goals of progress and development. Further, the state has to ensure that the process of knowledge diffusion among its citizenry will shore up its legitimacy rather than undermine its authority; while the incumbent government has not been known to crack down on any form of technoscientific knowledge, it has become much more prosecutorial over knowledge that represents, even if superficially, an opposition to its ideology and method of governance (Brown, 2007).

However, that does not mean that all forms of scientific research were given equal standing, for the state's practice of prioritarianism ensures the privileging of certain knowledge types over others. If military funding in the US had produced agnogenesis by advancing certain knowledge areas while allowing other areas to languish (Proctor, 2008), the same could be said about Malaysia's R&D policies. On the other hand, the aspiration towards epistemic generation is defined within the second instance of knowledge transfer for confronting agnotology, especially in the case when the knowledge transferred is blackboxed and derived from a larger body of knowledge hidden to those outside the inner circle of production; the recipients of the blackboxed knowledge reproduce the practice of secrecy during the epistemic generation phase, in belief that this would provide them an edge in a competitive economy.

At the same time, technoscientific progress does not erase ignorance, because agnotology could still be propagated through technocratic policing that narrow inquiries to knowledge seen as immediately translatable to a national developmental agenda, thereby creating situations where scientific and technical knowledge was only partially and incompletely transmitted. Moreover, the complex history of the scientific knowledge that could provide more background to the political and social nature of that knowledge was neglected during the process of transmission. In the end, recipients of said knowledge found themselves unable to respond more critically to the transmitted knowledge, which has the effect of hindering creativity and innovative thinking when it comes to intervening at a more foundational level. Agnotology is prevalent in postcolonial societies dependent on the transfer of scientific knowledge that were only partial transfers of expertise, especially when they were precluded from direct involvement in the creation of such knowledge (what Collins and Evans refer to as contributory expertise), and therefore, discouraged from deepening their knowledge acquisition to a more foundational level, especially if it is in the service of scientific curiosity.

Knowledge transfer as social engineering, and science and technology diplomacy, require the charting of internal and external factors and policies that position Malaysia along the contours of a world scientific system of a state that has gone from being a least developed country (LDC) to a second-tier newly industrialized one (NIC)[9] (Jomo, 1993). This is where Polanco's (1992) concept of short and long term movements in world-science (which he refers to as short time and long time) modelled after Braudel's world-economy system could be useful for structuring the timeline of Malaysia's

[6] The technocrat also embodies the expert and expertise, the latter signified by tacit knowledge and meta-expertise. Meta-expertise can be applied to groups of policy makers and decision-makers controlling the funding or support of science programmes, and who may, or not, be practicing scientists/technologists. However, a proper discussion of expertise is not within the scope of this article. See (Collins & Evans, 2007) and (Collins, 2016) for discussions on the issue.

[7] For those interested in learning more about the root meaning of the term, Robert Proctor provides a thoroughgoing explication in his introductory chapter to *Agnotology: the Making and Unmaking of Ignorance*.

[8] Agnotology, in the context of this article, is defined as ignorance stemming from certain social-epistemological conditions and/or choices. However, that definition of ignorance is relative to the kinds of knowledge that matter to the community judging their value; hence, negative knowledge in some epistemic (and even ontological) matters, to borrow a term of Knorr-Cetina, might not concern certain communities for whom deficit in these knowledge areas is not considered a loss.

[9] One of the concerns over Malaysia pertains to its ability to move out of the middle-income trap towards the production of higher value-added services and goods (Hutchison, 2016).

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science and technology movement, and identifying points of instability and constant fluctuation given Malaysia's continuing prevarication over how far to go with its nuclear programme, which conditions its investment into developing the required infrastructure and human resources. The world-science system is the embodiment of an epistemically charged longue durée explication of Malaysia's zones of technoscientific centres and the stages involved in the development of the nation's technoscientific agenda.

One example is seen in the alignment between scientific research and industrial technological needs. According to Felker and Jomo (1999), the reform of the innovation system in Malaysia from the late 1980s until the 1990s saw an integration of science and technology with industries to "create a Japanese-style, 'demand-driven' technology infrastructure focused on applied research and guided by specific sectoral needs; in contrast to an 'American-style' science-push system emphasising basic R&D and driven by academic curiosity or bureaucratic priorities" (p. 21). The pragmatist inclination was as much about putting resources behind projects with potentially quicker turnover as it was about attempting to become one of the centres of new technoscientific capital. A more concrete example of how interventions from external and international bodies have shaped the formation of Malaysia's technocratic valuation of science and technology is through consideration of Malaysia's relationship to the Atoms for Peace project, and its continual reliance on the IAEA for material and expert support. The kind of knowledge that was transferred would diffuse into the development of various sectors (from agriculture to medicine), with implications not only on how technoscientific knowledge was transferred to the citizens, but how the state proceeded with infrastructural development.

3. Epistemic transition, transplantation, localisation, and generation (ETTLG)

The first phase, which represents epistemic transition, is when an entity has to undergo a period of cultural adjustment and reconfiguration of beliefs and value systems to embrace an epistemic culture that might seem alien and different from what is native to the former; this phase requires consideration of circumstances conditioning the epistemic violence that alienates a community from its indigenous knowledge heritage while attending to how immigration and social assimilation could also render that heritage unstable. In the case of Malaysia, it also means operating with a new postcolonial identity that did not pre-exist British colonialism, all the while considering its relationship to a post-war world attempting to regain equilibrium.

The epistemic transition began with the establishment of the University of Malaya in Kuala Lumpur as an autonomous campus in 1959, after a decade of being conjoined to the Singapore campus, and the concomitant establishment of its independent Faculty of Science (Lim, 2013). The teaching of science began from year one, starting in the academic year 1959/1960, with laboratory instructions held at the Technical College and Victoria Institution (the latter two being junior colleges) leading to the graduation of the first cohort in 1963 (Lee & Moo, 1977). The growing number of graduates enabled the Malaysian government to send some of their promising students abroad for graduate studies by the 1970s; some returned to staff University of Malaya as well as the other new public universities that were being established. At a regional level, the Association of the Southeast Asian Institutions of Higher Learning had been set up by 1956,[10] with its first newsletter appearing in 1957. However, when a seminar on Mathematics and the Physical and Natural Sciences was held in Vietnam in 1967 (Ford Foundation, 1961), Malaysia was not, at that time, one of the participants.[11] The seminar included a field trip to the Atom Energy Centre at the University of Dalat, in Vietnam, and therefore, is indicative of how nuclear science research had taken root in Southeast Asia.

While the stage was being set at a local level, more politically advanced international actors with their own agenda seized the opportunity to intervene just as the national R&D policies of the emerging nations were being formulated. That was how Malaysia got started in its nuclear programme through Atoms for Peace. The programme was conceived to support dissemination of technological knowledge to emerging nations as a form of science and technology diplomacy, while keeping the recipient sufficiently dependent. The knowledge source was the US National Laboratories, which was instrumental in the development of research reactors, various radiation counters and detection tools, synchrotrons, cyclotrons, and accelerators; the work done there prepared the way for the development of the superbomb programme (York, 1976) that would not remain the exclusive prerogative of the US (Holifield, 1985), as well as programmes heralding the beginning of a practice in classifying scientific knowledge in the name of national defence and security.

The Atoms for Peace programme attempted to combat hostility while also forming allies through the careful knowledge diffusion, which inadvertently spread the culture of secrecy to beneficiary societies undergoing epistemic transitions, a culture that would then be localized in the beneficiaries' nuclear programmes. Galison (2010) details the rise of US's Atomic Energy Act, first ratified in 1946 to control how information pertinent to technological advancement in nuclear physics could be disseminated, amidst the protests of scientists. Therefore, anyone who "communicates, transmits, or discloses restricted data with the intent to injure the United States or secure advantage to a foreign nation could be punished by death or life imprisonment. Anyone who moves the restricted data with 'reason to believe' that their communication, transmission, or disclosure will injure the United States or secure advantage to a foreign nation could face up to 20 years in jail and/or up to a $20,000 fine" (p. 952). However, over the next eight years, declassification proceeded gradually, so that advances in nuclear instrumentation, mathematical techniques, accelerators, reactors, and nuclear medicine became more accessible. By the 1950s, Congressional hearings led to a significant revision of the act in 1954 that allowed partial exchanges with foreign countries while liberalizing certain patent provisions that coincided with the establishment of the Atoms for Peace programme in 1954, a programme that Krige (2006) refers to as a "polyvalent policy initiative".

According to Osgood (2006) and Krige (2006), the Atoms for Peace is a programme that aimed to control public sentiments regarding the national nuclear weapons programme while dealing with anti-communism paranoia (a paranoia that also beset much of Southeast Asia at the time); the programme coincided with the Eisenhower administration's need to curtail nuclear stockpiling by the Soviet bloc by encouraging, on the surface, the use of fissible materials from available uranium stockpile for peaceful purposes. In actuality, Eisenhower was engaged in one of the most massive weapons build-ups in US (perhaps even world) history. At the time he took office, the US had only 841 nuclear weapons. By the end of his presidency, it was estimated that the number had gone up to

[10] See (The Association of Southeast Asian Institutions of Higher Learning, n.d.).

[11] The participants were institutional representatives from Singapore, the Philippines, Thailand, and Vietnam.

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18,683 (Krige, 2006, p. 162). Krige suggests that the detonation of the bomb Bravo, which vaporized three islands of the Bikini Atoll in Marshal Islands and produced in its wake civilian casualties out of the Japanese tuna fishing boat, *Lucky Dragon Five*, had contributed to the US impetus in propagating the nuclear-peace programme. Having directly experienced the destructive potential of thermonuclear weapons, and fearing competition from other emerging nations and the Soviet Union, the Eisenhower administration decided that controlled diffusion of nuclear knowledge was the best safeguard.[12] One could read this as a form of epistemic locking-in, laying down for state actors of emerging nations the parameters of their science and technology policies while discouraging their emulation of the same scientific practices and cultures that had enabled the generation of the nuclear technology in the first place. Therefore, by dictating the terms of science and technology policies of these newly independent and emerging states, the industrialized/former imperialists were effectively abrogating the epistemic sovereignty of these new nations. This would be the attitude underlying much of science and technology diplomacy from more advanced states to recipient states.

The Atoms for Peace programme that went hand in glove with the Eisenhower Administration's psychological warfare saw the establishment of the US Information Agency, and the transmission of books and other reading materials steeped in American values to identified recipients (Barnhisel, 2010), including Malaysia. With the Atoms for Peace programme in place by 1954, and the IAEA set up by 1957, the process of organizing what to classify and declassify was underway, beginning from 1955 with the first Geneva Summit, one intimately documented by Laura Fermi in *Atoms for the World*. The 1955 summit was supposed to represent the starting point of the superpowers' official act of disseminating declassified information. Eisenhower became the first president to test a pool-type reactor: this pool-type reactor was later relocated to Wuerenlingen in Switzerland (United States Atomic Energy Commission, 1958; Chastain, 1958).

The second Geneva conference in 1958 about doubled in size (from 3600 to 6300 strong in the number of attendees), and the initially classified results pertaining to thermonuclear reactions were also revealed for the first time. The US technical exhibits included full-size operating laboratory devices with two operating reactors, a computer facility, a radioisotope laboratory, a hydrogen bubble chamber, a whole-body radiation counter, and seven operating devices for research into thermonuclear reactions. Many technical exhibits and informational materials on display were prepared as publicity materials to demonstrate the US's nuclear diplomatic goals (United States Atomic Energy Commission, 1958). The 1950s saw the US occupying a lead position where nuclear technology was concerned (Cartwright, 1978). By the time of the second Summit, the TRIGA (Training, Research, Isotope Production, and General Atomic) reactor, also a pool-type reactor but touted as safer than previous generations of pool-type reactors, was already developed. This reactor would play a big role in nuclear technological transfer and transplantation to developing countries such as Malaysia.

Edward Teller, Freeman Dyson, and a group of young physicists designed the TRIGA reactor in the summer of 1956 for their friend Frederick Hoffman's newly established company, General Atomic. The new reactor design was meant to replace the usual reactor design influenced by the submarine-propulsion reactor programme under Admiral Rickover. Most importantly, the reactor was designed for operation by institutions and technicians without sophisticated knowledge of nuclear science and technology (Dyson, 2015). Incidentally, Teller had a major role as scientist-advocate for nuclear science in the Atoms for Peace programme that included advocating for the deployment of nuclear energy in Southeast Asia, exemplified by his 1975 lecture tour in Bandung, Indonesia (Teller, 1977). This was boosted by both the US's and other developing nation's anxiety over existing oil reserves, one spurred by a doctrine that equates socio-economic progress with ever-increasing energy consumption. The relation between energy and economic development is a constant point of anxiety for states grappling with the problem of finite energy resources to this day.

While assimilating the values of more advanced state actors, the transitioning state actors still have agency over what values they choose to identify with, although one could contest how much of that agency is possible. Since becoming a member of the United Nations Assembly, Malaysia has been active in calling for a ban on nuclear weapons testing, beginning with the then Deputy Prime Minister, Tun Dr Ismail Abdul Rahman (Malaya to A-powers: Halt Tests, 1958, p. 7). In the early 1960s, the Malayan cabinet ministers were protesting nuclear weapons tests and calling for disarmaments (Anti-nuclear group set up, 1961, p. 9; Malaya's U.N. Call to Outlaw Nuclear Weapons, 1961, p. 7). At the same time, Malaya was interested in the potential of nuclear power even before 1957, probably because its Southeast Asian neighbours were also negotiating their own nuclear power plants (Malaya Eyes Nuclear Power, 1957, p. 5). As early as 1955, the (interim) Singapore government bid for a nuclear research site to be located in Johor, the southernmost state of Malaysia, through the Colombo Plan's technical assistance programme (S'pore Bid for A-plant, 1955, p. 1). However, Malaysia would not make an official commitment over where it stood when it came to nuclear energy, not even after an official of IAEA had visited in 1979 to convince the former (Harness N-energy Malaysia urged, 1979, p. 12). Further, the contradictory statements of its ministers, as seen in the news articles published between the 1970s and 1980s, indicate the Malaysian government's vacillation over the issue, possibly due to negative public reception stemming from radiation phobia.

With the stage set by epistemic transition, the second phase involving epistemic translation and localisation began. This involves a controlled transfer of blackboxed scientific knowledge to Malaysia via the IAEA, which means that the maintenance of knowledge obtained from more advanced technoscientific centres and adapted to local conditions would be required. The second phase takes place after the state actor has embedded a set of values during its transitional phase, and proceeds to operate by that set of values. Scientific resources in the 1960s and 1970s came from the UK and the US, through their donations of textbooks, reference books, and journals, many of which are still maintained by the institutions that received them, and representative of the tangible outcome of knowledge transplantation.[13] Galison (2004) argues that there are two kinds of secrets: one that is subjective, in that the secrets are "compact, transparent, arbitrary, changeable, and perishable" while the second category of secrets are objective, or "diffuse, technical, determinable, eternal, and long-lasting qua secrets" (p. 233). At the intersection of these two types of secrets is the kind of technical knowledge that will not threaten the balance of power and is therefore safe for propagation.

The blackboxed objective scientific knowledge consists of technical knowledge that would only permit recipients of such knowledge limited access to the ontology of such knowledge. The

[12] The Russians also conducted their version of the Atoms for Peace programme among socialist states, but that will not be discussed here.

[13] I found that these materials were still stored at the Nuclear Agency of Malaysia, University of Malaya, and the National University of Malaysia, as each of them were early beneficiaries of the gifts programme.

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epistemic locking in, as well as agnogenesis shaped by selective transfer of knowledge, causes the knowledge recipient to remain dependent. An example is the deployment of SCRAM (Study of Core Reloads using an Analytical Model) that had been developed in the US – the version that was eventually deployed for reactor control by the nuclear agency in Malaysia was developed by a doctoral student at the University of Pennsylvania – through localisation that involved minor tweaks (by inputting customised parameters required by Malaysia's TRIGA reactor). Even further troubleshooting of the code required the help of allies from another nation, which was Japan in this case (Gui, 1984). Knowledge transfer builds dependency when implementation is not accompanied by access to building blocks of that knowledge.

In addition, from the last century up to the beginning of the twenty-first century, technical assistance programmes, aids, and short-term placements of experts in the recipient countries heavily influenced national technoscientific policies. These aids were either multilateral or bilateral, depending on the administering agencies and states. A significant portion of the aid came in the form of technical assistance with the intent of overcoming skills scarcity, although one might question whether these skills will add to the advantages of the developing states, or merely feed the interest of the more advanced states extending such aids. Moreover, as de Silva (1970) argues, the aid itself could lead to problematic linkages with former colonisers, ensure continuing dependency, and bring in irrelevant training and technologies, as well as create an outward brain drain from developing to more developed countries due to incompatibility between the training and demand, if not better job prospects elsewhere. In other words, the process of transplantation does not always produce effective localisation if the agenda of development is externally influenced, rather than the result of an organic development. One might suspect that the lack of generative localisation also stems from a mechanism of knowledge diffusion that blackboxed the fundamentals of the knowledge.

The mid-1960s involved transplantation of technology and knowledge in a manner that is piece-meal and not always effective: the training of staff did not correlate with the establishment of facilities and sufficient infrastructural support for putting that training to an expedient end. The mid-1960s until the end of the 1970s were characterised by an emphasis on technical skills training for a majority of the workforce. A number of those with technical training ended up in the private sector, not necessarily applying the technical training they had received although they might utilise the skills imparted by that training (Ford Foundation, 1965; Lee & Moo, 1977). The Colombo plan ensured, by the mid-1960s, that there were Malaysians who could serve in the technical fields of medicine, engineering, science and higher education. However, graduate level training sponsorship was only made possible with the establishment of the Public Service Department, beginning from 1970. [14] Both experimental and theoretical scientific work was in full swing by the latter half of the 1970s (Tan & Ong, 1976), although existing facilities for experimental work were poor (Ford Foundation, 1962) and still under construction up to the 1970s (Hussain, 1977). For instance, by the mid-1980s, infrastructures for developing radiation technologies were still inadequate, despite the application of radiation techniques since at least 1980, therefore making the transfer of such technologies into industry difficult (Muslim, 1986). Malaysia also shared with India the lack of sufficient provision of reactor infrastructures, such as for the development of nuclear probes for other nuclear analytical approaches beyond the conventional neutron activation analysis (Gangadharan, 1983).

As epistemic localisation took place in the second phase from the late 1970s up to the 1980s, the Malaysian government's social engineering was focused on ensuring that industry's interest did not supersede the former's interest; however, industry's investment in technological development, including that by the multinational corporations based in Malaysia, was low (Felker & Jomo, 1999). At the same time, there were concerns that a heavy-handed technocratic state intervention could lead to a "competence-bottleneck" making hierarchical procedural governance, meant for ensuring sufficient transparency in the composition of networks, difficult, as the state may "prevent, delay, or shape in a specifically distorted manner" the development of a technological corridor (a conglomeration of public/private networks). This "competence-bottleneck" could also contribute to a depreciation of knowledge, and even elicit resistance from the firms involved when state and commercial interests conflict (Meyer-Stamer, 1999, p. 45).

The difficult relationship between the state, industry, and the citizenry is even more pronounced in the case of the nuclear programme. The deployment of nuclear technology to manufacturing, agriculture, food processing, and other forms of applied sciences intended towards industrial applications were channelled to industry by way of various agencies, including the national nuclear agency. Even if much of the knowledge produced involved the maintenance of an existing epistemic framework of operation, the government maintains the practice of classifying documents relating to the nuclear project, or any materials pertaining to the nuclear programme — a culture of secrecy instituted at the time of epistemic transition. However, in this case, secrecy is more about exerting control over information and maintaining political legitimacy, although decisions made over what to reveal, and when the revelation should take place, were aimed at managing public perceptions and expectations. The lack of epistemic transparency, public understanding of the science, and trustworthy disclosure from the government, ignited controversies over issues pertaining to the management of radioactive wastes, such as Bukit Merah in 1985 and the Lynas case this century (both involving the mining of rare earth metals).

Given that Indonesia was already the first state in Southeast Asia to have embraced nuclear technology, Malaysia was not the first recipient of the nuclear programme within Southeast Asia. Indonesia has a working 250 kW TRIGA reactor since 1965 that was already upgraded to 1000 kW (Arbie & Supadi, 1995) by the time the Malaysian delegates visited the country's nuclear reactor facility in 1972. The Philippines had another research reactor before the TRIGA was constructed through the Atoms for Peace programme, acquired in 1955 (Bernido, Santos, & Leopando, 2007; Dera Rosa & Aleta, 1992). Vietnam had a TRIGA MK II research reactor since 1963, with a Russian core that was since integrated into that reactor (Ngo & Vu, 2000). Finally, Thailand had a TRIGA MK III reactor since 1977 (Aramrattana & Busamongkol, 1999). Incidentally, in January 1970, a nuclear energy seminar was held in Jogjakarta, co-convened by the Badan Tenaga Atom Nasional (BATAN) and the Direktorat Djenderal Tenaga dan Listrik that focussed on the development and future prospects of nuclear energy in Indonesia.[15]

Tun Dr Ismail's visit to the Indonesian national atomic reactor in Bandung in March 1972 (Cheah, 1972) to learn about the potential

[14] Information relating to the scholarship scheme was obtained from preliminary interviews with three scientists. At the time of writing, I have yet to obtain the statistical data requested from the Public Service Department of Malaysia with regard to the kinds of graduate training that were sponsored under the department's scholarship scheme between 1970 and 1990.

[15] A proceeding has been published by BATAN.

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for harnessing that technology in agriculture resulted in the establishment of CRANE (Centre for the Application of Nuclear Energy) the same year. In a little less than a decade, the government announced plans for building a training centre at what became known as PUSPATI (Pusat Penyelidikan Atom Tun Ismail/Tun Ismail Atomic Research Centre), with aspirations to produce a new generation of nuclear workers (Training in Nuclear Know-How for Workers, 1981, p. 14). The process began by having trainees and students sent abroad for advanced skills training. The annual report of PUSPATI noted that nine of its technical employees had received work-placement training at the Australian Atomic Energy Commission Research Establishment (AAEC), three with the Bhabha Atomic Research Centre (BARC), three with General Atomic, and four with the Japanese Atomic Energy Research Institution (JAERI) (Puspati, 1981, pp. 1–80).

In addition, four more were locally trained in locations such as the General Hospital of Kuala Lumpur, the Institute of Medical Research, and Malaysia's Metrological Services. By 1983, Malaysia was already playing host to an international conference on the effective utilization and management of nuclear reactors (Proceedings of the Seminar on the Effective Utilisation and Management of Research Reactors, 1983). Most of the technical assistance from that period concentrated on safeguards (Pathmanathan, 1978; United States Department of State, 1987); PUSPATI was concerned with radiation measurements of nuclear fallouts from thermonuclear weapon tests elsewhere, and also in locating the best site for the establishment of its national reactor site. Even today, Malaysia has a centre in Pahang for measuring radionuclide no. 42 activity, while also offering technical support for the verification of fallouts stemming from thermonuclear weapon tests.[16]

The first nuclear science faculty was established at the National University of Malaysia (UKM) in 1980 (Program Sains Nuklear, n.d.). A TRIGA Mark II, operating at 1 MW, was obtained through an agreement signed between the Malaysian government, the US government, and the IAEA on 22 Sept 1980,[17] more than a year after the signing of an agreement with General Atomic. Since a proper site to house the reactor was not completed until the end of 1981, the reactor could not be commissioned until June 1982. The first fission-chain criticality was achieved in June 28, 1982.[18] To legislate the operation of all facilities or installations connected to nuclear technology, the Atomic Energy Licensing Act was gazetted in June 1984.[19] Given the pervasive conception of science and technology as handmaidens of development, there was still not much political motivation, up until the early 1990s, to develop scientific infrastructures that encouraged R&D in basic nuclear science research, even if that did not translate to no scientists doing such research.[20] Further, due to the imbalance between available expertise and infrastructures to support the development of that expertise, it was not uncommon for many scientists returning to Malaysia to find that they had to deploy the skills developed within their original area of research in another field more readily available in Malaysia.

By the mid-1980s, an intensification of research in priority areas (IRPA) scheme was established under the five-year, 1986–1990 Fifth Malaysian Development Plan, with the Nuclear Energy Unit's research programme prominently featured in this plan. In 1988, the Malaysian government spent MYR 4.87 mil, followed by MYR 4.02 mil in 1989, and MYR 3.75 mil in 1990, the last amount representing a decrease in government funding. If the agricultural and industrial sector set out on almost equal footing, much of the resource allocation went to industrial programmes by 1990, with static amounts dedicated to nuclear medicine and also an increasing amount dedicated to strategic programmes (what exactly they are is not stated in the document). Interestingly, the report on the IRPA scheme was already criticising the bureaucratic requirements of grant applications for slowing down the progress of science as scientists had to spend an inordinate amount of time writing grant applications every year for a mere pittance (Unit Tenaga Nuklear, 1990).

The setting up of the IRPA scheme coincided with the government's Look East policy; by the second half of the 1980s, Malaysia was turning to Japan for the acquisition of technological knowledge, although a trade agreement had been established with Japan since the early 1960s (Unit Teknologi Nuklear, n.d.). Therefore, when Singapore hosted the aforementioned first Asia-Pacific Physics conference, it was organized with leadership from the Japanese physics community. The papers from the proceedings illustrate Malaysian physicists' attempt at participating in as near an equal footing as possible, even if the projects they were working on involved small-scale calculations and problem solving, and seemed relatively unambitious from a global standpoint.

Despite the existence of local scientific journals since the 1970s, the publication quality was largely sophomoric, with professionalization happening only towards the end of the 1980s. The national nuclear agency, which underwent a few name changes from CRANE to PUSPATI to Nuclear Energy Unit to the Malaysian Institute for Nuclear Technology Research (MINT) before settling into what it is today, the Malaysian Nuclear Agency, publishes its own in-house journal, *Jurnal Nuklear Malaysia*, covering topics of interest to the local nuclear science and technology community. The establishment and growth of the nuclear programme through infrastructural construction, reactor commissioning, methods of informational dissemination, and the embedding of nuclear technology and knowledge within the agenda of national development, signify epistemic transplantation and localisation.

The third phase of epistemic generation for Malaysia's nuclear programme is mostly concentrated at the intra-state level, or

[16] Information was obtained from a circular sent out by the Nuclear Agency of Malaysia to National University of Malaysia (UKM) in April 21, 2016.

[17] Although the reactor was purchased, the accompanying enriched uranium was received as a gift. This was noted in the information circular 287 of the IAEA and a short news item ($11,000 gift for atom centre, 1980). There could be either a misprint on the headline or body of the article, as the article refers to the grant as $110,000, which is a sizeable amount. The agreement between the agency and the IAEA as laid out in the circular stipulated that the US would supply approximately 24.76 kg of uranium isotope-235 enriched to approximately 19.9% by weight as fuel rods and 7.6 g of uranium isotope-235 enriched to approximately 93% by weight for use in the neutron detectors. The transfer of uranium appears to be of the value of $50,000 per annum, which would mean that the $110,000 is the more plausible number if the transfers were being made in instalments. As stated in Article V of the circular (The Text of the Agreement of 22 September 1980 Concerning the Agency's Assistance to Malaysia for the Establishment of a Research Reactor Project, 1983) which lists out the payment made by the Malaysian government for the establishment of the research reactor project, the Malaysian government appeared to have paid for the purchase of the TRIGA Mark II reactor from General Atomic with facilitation by the IAEA.

[18] The Philippines also acquired the TRIGA in the same decade as Malaysia, although it had acquired a research reactor of a different kind in 1963. Its TRIGA reactor has since been decommissioned.

[19] At the time of writing, in preparation for Malaysia's possible investment in nuclear energy, work is underway to update the legislature governing the deployment of nuclear technology that would include safeguards for nuclear power plants.

[20] Local science journals from between the late 1970s until the 1980s indicated that there were attempts to do foundational research in the physics of another area close to nuclear science, particle physics, despite there being no facilities whatsoever for doing experimental work in the area. Malaysia was also not a direct participant at CERN until it became a part of the CMS collaboration in 2013 (information obtained from private communication with Malaysia's Academy of Science).

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among individual collaborators if international partners are involved; nuclear knowledge moves from the research institution/nuclear agency/and even university departments to both public and commercial sectors. This is when efforts at eradicating epistemic dependency and agnotology become serious. Although serious efforts are made towards the production of own technologies, there is still some dependency on foundational knowledge from other polycentres of nuclear research. At the same time, Malaysia's nuclear programme strives to be competitive in the development of nuclear technologies for industry, health, agriculture, hydrology, environment, and solid waste treatment. One could consider the third phase as having developed, albeit in a very minor way, since the 1980s. Even as nuclear knowledge was in the process of being localized, initiatives were taken to transfer that knowledge beyond the confines of a closed group of recipients in minor ways, through early versions of public science communication. For instance, there were proposals for building a quiz board using the equivalent of a hobby kit setup (Rashid & Khair, 1984) and the construction of an electronic physical model of a neutron chain-reaction of three generations that included the use of sound effects generated with a tape recorder (Rashid, 1982); these proposals are proto versions of today's maker culture doubling as education outreach. Technocrats continue to forecast the potential of nuclear technologies and nuclear energy for Malaysia, even as other technologies are being developed.[21]

One of the national nuclear programme's achievements was the establishment of a multipurpose gamma irradiation plant for R&D and industry use (one that exceeds a lower capacity 1977 version from an Australian manufacturer of healthcare products, Ansell), with the capacity of two-million Ci or 2000 kCi, using Cobalt-60; two more gamma ray irradiation facilities of a much lower capacity were built in 1995 and 2010, with expertise continuously being developed to produce the needed components locally to reduce expenditure and obtain more control.[22] While irradiation of food produce is becoming a regular practice today, the late 1990s up to the turn of the twenty-first century saw intensive campaigns for the public acceptance of that technology in Malaysia, which also means transferring knowledge regarding radiation safety to food producers (Food and Environmental Protection Section, 2001). Further, there is long-term intention in upgrading the capacity of the current reactor (of 1 MW) to 20 MW by 2026 (Muhd Yunus, 2013).

Much of the revenue generated at this point had been in consultancies and services, trainings, and commercialization of the technologies, although the operating costs appear to supersede the revenues, even up to the projected year of 2030 (Muhd Yunus, 2013), perhaps because Malaysia still requires the transfer of expert knowledge and technologies from outside of Malaysia and is not yet at the stage of independently adding value. Now that Malaysia is moving towards the construction of its own nuclear power plants, it aspires to be a hub for dissemination of nuclear information and technical support provision. The supply of nuclear power, and expertise pertaining to its maintenance, is a long-term plan for enhancing the state's nuclear energy capability (Muhd Yunus, 2013).

Malaysia's technocrats are looking into ways for improving local capacity for supporting the state's venture into nuclear power production. Since 2010, the College of Engineering at a private university, Universiti Tenaga, has been involved in the development of technical elective courses in nuclear engineering and technology in its Nuclear Engineering Department, with input from Texas A&M's University and Chulalongkorn University in Bangkok (Hamid et al., 2015). However, the demand for such courses is still low, which could be attributed to their newness, perception of their high level of difficulty (therefore jeopardising the student's grades), and not being particularly useful for the job market. Nevertheless, efforts are being made to improve and develop the courses at that university further, and at the Technological University of Malaysia (UTM).[23]

Therefore, the epistemic generation phase is one where the nation is struggling to define its place within the production of technoscientific knowledge, particularly in terms of what values it could re-transmit to the global pool of knowledge from whence it has drawn its epistemic resources. At the same time, one might ask whether only major contributions to basic science should be privileged as valuable contributions to technoscientific developments, to the exclusion of other forms of inquiries and research that could produce findings that provide insight to foundational questions. This is an important consideration for those supporting scientific research in cultures without a long tradition of foundational scientific inquiries, but who are developing strategies for making original contributions in such inquiries. Finally, it is crucial to inquire into the value of a nuclear science programme in contributing to the technoscientific infrastructures of a developing state; will nuclear energy solve the energy crisis of a still-developing state, or bring about new problems beyond liabilities from contamination?

4. Conclusion

The ETTLG model attempts to theorise the networks of glocal knowledge, which involve the adaptation of global and universal forms of knowledge to local conditions as they weave through different technoscientific and socio-political landscapes. The development of the nuclear programme in Malaysia is used as a detailed case example because its technoscientific character provides ample material for amplifying the three developmental phases articulated by the model while serving as evidence to back up the claims of the model.

There are three main events in the development of Malaysian nuclear science and technology programme that are captured through the three-phase/three-tier structure of the model: the epistemic transition phase is centred on how the international turn of events, coupled with the birth of a national modernisation project, prepared the ground for the establishment of the programme and the mobilisation of knowledge (and technological) transfer; the epistemic transplantation and localisation each represent a period when the programme was in the process of taking root, while accounting for local and transnational politics that produced the operating conditions for knowledge and technological transfer; the epistemic generation stage takes place when the programme aspires to greater self-reliance and sustainability, and to be more generative of technological developments that could also be sold, or transferred, to other sectors or state actors. However, the third epistemic stage is still a work in progress as it is framed within still evolving technoscientific conditions undergoing epistemic transitions in response to local and global conditions.

[21] There is on-going R&D on solar batteries and electric cars, among others, but I will not discuss them here.

[22] See the Unit Tenaga Nuklear, 1989; Electron Accelerator Application: Gamma-ray Irradiation Facilities for Commercial Use (including R&D), n.d.; and (Gamma Irradiator, n.d.).

[23] See <https://www.iaea.org/nuclearenergy/nuclearknowledge/Events/2015/2015-07-28-31-TM-INMA/Presentation/23-Khaidzir-Univ-tekno-Malaysia.pdf>. Accessed October 27, 2016.

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Nevertheless, the model aims not only to represent the case of the nuclear programme in Malaysia, but other state actors with socio-political, economic, and technoscientific agendas that either resemble or parallel that of Malaysia. The context of knowledge transfer involves both macro-level circulation of a technoscience that might appear neutral from a micro-perspective, yet is dependent on the conditions of institutional politics. The choice of what technoscientific knowledge to transfer or circulate outside their points of origins is never sufficiently determined by disinterestedness or curiosity, but by the potential for capital, or advantages, to be gained. Therefore, the form in which the knowledge is transferred may belie the ideals generating that knowledge in the first place.

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References

$11,000 gift for atom centre. (1980, September 25). *The straits times* (p. 16).
Alvares, C., & Sachs, W. (2010). Science. In *The development dictionary: A guide to knowledge power (second, pp. 243–259)*. New York & London: Zed Books.
Anti-nuclear group set up. (1961, September 14). *The straits times* (p. 9).
Aramrattana, M., & Busamongkol, Y. (1999). *Current status of nuclear research reactor management and utilization program in Thailand* (No. JAERI-Conf–99–9006). Japan.
Arbie, B., & Supadi, S. (1995). *Status report of indonesian research reactors*. International Atomic Energy Agency (IAEA) (No. INIS-XZ-C–006)
Arima, A., Chew, C. K., Ninomiya, T., Ong, P. P., Phua, K. K., & Tan, K. L. (Eds.). (1984). *Proceedings of the first Asia-Pacific physics conference 1983* (Vols. 1–2)Singapore: World Scientific Publishing Co. Pte. Ltd.
Barnhisel, G. (2010). Cold warriors of the Book: American book programs in the 1950s. *Book History, 13*, 185-217. https://doi.org/10.1353/bh.2010.0010
Bernido, C. C., Santos, F. L., & Leopando, L. S. (2007, October). Decommissioning the Philippine research reactor (under R2D2P): Updates and challenges. In *Powerpoint presented at the technical meeting on establishment of an international decommissioning network*. Vienna.
Böcher, M., & Krott, M. (2016). *Science makes the world go Around: Successful scientific knowledge transfer for the environment*. Switzerland: Springer International Publishing.
Brown, G. K. (2007). Making ethnic citizens: The politics and practice of education in Malaysia. *Education, Ethnicity and Conflict, 27*(3), 318-330. https://doi.org/10.1016/j.ijedudev.2006.12.002
Bucchi, M. (2009). *Beyond Technocracy: Science, politics, and citizens*. Dordrecht: Springer.
Carrier, M. (2011). Knowledge, politics, and Commerce: Science under the pressure of practice. In A. Nordmann, & M. Carrier (Eds.), *Science in the context of application* (pp. 11-30). Dordrecht: Springer Science +Business Media, B.V.
Cartwright, P. (1978). International nuclear technology transfer. *Power Engineering, 82*(8), 62-64.
Chastain, J. (1958). *U.S. research reactor operation and use*. MA: Addison-Wesley.
Chatzis, I. (2016, October 10). *IAEA starts review of Malaysia's nuclear power infrastructure development [Text]*. Retrieved October 14, 2016, from https://www.iaea.org/newscenter/news/iaea-starts-review-of-malaysias-nuclear-power-infrastructure-development.
Cheah, B. K. (1972, March 14). Ismail learns all about usage of atomic energy. *The Straits Times*, 9.
Collins, H. (2016). Studies of expertise and experience. *Topoi*, 1-11. https://doi.org/10.1007/s11245-016-9412-1
Collins, H., & Evans, R. (2007). *Rethinking expertise*. Chicago & London: University of Chicago Press.
Dera Rosa, A. M., & Aleta, C. R. (1992). *Research reactor utilization in the Philippines* (No. JAERI-M–92–9028). Retrieved from INIS.
Dyson, F. (2015). Chapter 3.5: Edward Teller (1908-2003). In *Birds and Frogs: Selected papers 1990-2014* (pp. 127-137). Singapore: World Scientific Publishing Co. Pte. Ltd.
Electron Accelerator Application: Gamma-ray Irradiation Facilities for Commercial Use (including R&D). (n.d.). Retrieved October 24, 2016, from http://www.fnca.mext.go.jp/english/eb/e_gamma.html.
Felker, G., & Jomo, K. S. (1999). Introduction. In K. S. Jomo, & G. Felker (Eds.), *Technology, competitiveness, and the state* (pp. 1-37). London & New York: Routledge, Taylor & Francis Group.
Fermi, L. (1957). *Atoms for the world: United States participation in the conference on the peaceful uses of atomic energy*. Chicago, IL: The University of Chicago Press.
Food and Environmental Protection Section. (2001). Consumer acceptance and market development of irradiated food in Asia and the Pacific. In *Final research coordination meeting*. Vienna: International Aotmic Energy Agency.
Ford Foundation. (1961). *Malaya – university of Malaya. Ford foundation records, international division*. South and Southeast Asia, Kuala Lumpur: Malaysia Field Office Files. Box 6.
Ford Foundation. (1962). *Colombo plan – technical assistance; Colombo plan. Ford foundation records, international division*. South and Southeast Asia, Kuala Lumpur: Malaysia Field Office Files. Box 2.
Ford Foundation. (1965). *Manpower/malaya. Ford foundation records, international division*. South and Southeast Asia, Kuala Lumpur: Malaysia Field Office Files. Box 6.
Galison, P. (2004). Removing knowledge. *Critical Inquiry, 9*, 229-243.
Galison, P. (2010). Secrecy in three acts. *Social Research: An International Quarterly, 77*(3), 941-974.
Gamma Irradiator. (n.d.). Retrieved October 24, 2016, from http://www.nuclearmalaysia.gov.my/new/RnD/energy/nuclear/gammaIrradiator.php.
Gangadharan, S. (1983). *Activation analysis with reactor neutrons (pp. 7–11). Presented at the seminar on effective utilisation and management of research reactors, unit Tenaga nuclear*. Prime Minister's Department.
Goel, R., & Rustagi, N. K. (2006). Increasing competitiveness through knowledge transfer in developing countries. *Advances in Competitiveness Research, 14*(1), 77-89.
de Greiff, A., & Olarte, M. N. (2006). What we still do not know about South-North technoscientific exchange. North-centrism, scientific diffusion and the social studies of science: North-centrism, scientific diffusion, and the social studies of science. In *The historiography of contemporary science, technology, and Medicine: Writing recent science* (pp. 239-259). London & New York: Routledge.
Grote, M. (2015, July 8). *What could the 'longue durée' mean for the history of modern sciences?*. Retrieved from https://halshs.archives-ouvertes.fr/halshs-01171257.
Gui, A. A. (1984). *Pengubahsuaian SCRAM - kod komputer untuk kiraan pembakaran bahanapi reaktor TRIGA PUSPATI/SCRAM's modification - computer code for the calculation of the PUSPATI's TRIGA Reactor's fueld load*. Bangi, Selangor: Unit Tenaga Nuklear (Current Project Report)
Gwynne, P. (2011). Malaysia seeks economic success based on science and technology. *Research-Technology Management, 54*(5), 2+.
Hamid, N. A., Mohamed, A. A., & Yusoff, M. Z. (2015). Progress of teaching and learning of nuclear engineering courses at college of engineering, Universiti Tenaga nasional (UNITEN). *AIP Conference Proceedings, 1659*(1). https://doi.org/. https://doi.org/10.1063/1.4916843
Harness N-energy Malaysia urged. (1979, November 14). *The business times*.
Harris, S. J. (2011). Long-distance corporations, big sciences, and the geography of knowledge. In S. Harding (Ed.), *The postcolonial science and technology studies reader* (pp. 61-83). Durham, NC: Duke University Press.
Holifield, C. E. (1985). The birth of the peaceful atom. In J. F. Pilat, R. E. Pendley, & C. K. Ebinger (Eds.), *Atoms for Peace: An analysis after thirty years* (pp. 51-66). Boulder, CO: Westview Press, Inc.
Howlett, R. J. (2011). *Innovation through knowledge transfer*. Berlin & Heidelberg: Springer Verlag.
Humphreys, P., & Imbert, C. (2012). *Models, simulations, and representations*. New York & London: Routledge.
Hussain, S. A. (1977). Physics education in universities. In S. Lee, F. T. Lee, K. S. Low, & S. P. Moo (Eds.), *Physics education and research from the viewpoint of national development* (pp. 17-19). Kuala Lumpur: Jabatan Fizik Universiti Malaya.
Hutchison, F. E. (2016, August 23). *Is Malaysia really out of the middle-income Trap? [Commentaries]*. Retrieved October 21, 2016, from https://www.iseas.edu.sg/medias/commentaries/item/3811-is-malaysia-really-out-of-the-middle-income-trap-a-commentary-by-francis-e-hutchinson.
Jomo, K. S. (1993). *Industrializing Malaysia: Policy, performance, prospects*. London & New York: Routledge, Taylor & Francis Group.

Krige, J. (2006). Atoms for peace, scientific internationalism, and scientific intelligence. *Osiris: Global Power Knowledge: Science and Technology in International Affairs, 21*(1), 161-181.

Lee, F. T., & Moo, S. P. (1977). Data on careers of physics honours graduates 1962-1976. In S. Lee, F. T. Lee, K. S. Low, & S. P. Moo (Eds.), *Physics education and research from the viewpoint of national development* (pp. 49-54). Kuala Lumpur: Jabatan Fizik Universiti Malaya.

Liew, J. T. (2016, October 11). Malaysia's nuclear energy plans remain intact. *The Edge*. Retrieved from http://www.theedgemarkets.com/my/article/malaysia%E2%80%99s-nuclear-energy-plans-remain-intact.

Lim, C. T. (2013). *University of Malaya 1949-1985: Its establishment, growth, and development*. Kuala Lumpur: University of Malaya Press.

Lin, Z. (2000). Organizational restructuring and the impact of knowledge transfer. *Journal of Mathematical Sociology, 24*(2), 129-149.

Malaya Eyes Nuclear Power. (1957, June 3). *The straits times*.

Malaya to A-powers: Halt Tests. (1958, October 24). *The straits times* (p. 7).

Malaya's U.N. Call to Outlaw Nuclear Weapons. (1961, November 15). *The straits times* (p. 2).

Mehos, D. C., & Moon, S. M. (2011). The uses of Portability: Circulating experts in the technopolitics of cold war and decolonization. In G. Hecht (Ed.), *Entangled Geographies: Empire and technopolitics in the global cold war* (pp. 43-74). Cambridge, MA: MIT Press.

Member States | International Atomic Energy Agency. (n.d.). Retrieved May 29, 2016, from https://www.iaea.org/about/memberstates.

Meyer-Stamer, J. (1999). Technology, competitiveness and governance. In K. S. Jomo, & G. Felker (Eds.), *Technology, competitiveness, and the state* (pp. 38-52). London & New York: Routledge, Taylor & Francis Group.

Morrison, M. (2015). *Reconstructing reality*. Oxford & New York: Oxford University Press.

Muhd Yunus, M. N. (2013, March). Growing nuclear applications for sustainable development of Asian countries. In *Powerpoint presented at the Fukui international HRD seminar.* Tsuruga. Retrieved from https://fihrdc.werc.or.jp/achievement/13-pdf/Session4/4%20Malaysia.pdf.

Muslim, N. (1986). Nuclear science and technology in developing Countries: Potential and perspectives. In *Significance and impact of nuclear research in developing countries* (pp. 3-14). Athens, Greece: International Atomic Energy Agency.

Narteh, B. (2008). Knowledge transfer in developed-developing country interfirm collaborations: A conceptual framework. *Journal of Knowledge Management, 12*(1), 78-91. https://doi.org/10.1108/13673270810852403

Ngo, Q. V., & Vu, D. N. (2000). *Country report present status and need of human resource development in nuclear field in Vietnam* (No. JAERI-Conf—2000-014). Japan.

Nilsen, V., & Anelli, G. (2016). Knowledge transfer at CERN. *Technological Forecasting and Social Change, 112*, 113-120. https://doi.org/10.1016/j.techfore.2016.02.014

Nordmann, A., Radder, H., & Schiemann, G. (2011). Science after the end of Science: Debating claims of an epochal break. In *Science Transformed? Debating claims of an epochal break* (pp. 1-18). Pittsburgh, PA: University of Pittsburgh Press.

Osgood, K. (2006). *Total cold War: Eisenhower's secret propaganda battle at home and abroad*. Lawrence, Kansas: University of Kansas.

Pathmanathan, M. (1978). *Nuclear technology transfer and international safeguards: A case study of Malaysia. Presented at the application of science and technology to development*. Kuala Lumpur.

Polanco, X. (1992). World-Science: How is the history of World-Science to be written? In P. Petitjean, C. Jami, & A. M. Moulin (Eds.), *Boston studies in the philosophy of science: Vol. 136. Science and empires* (pp. 225-242)Dordrecht: Springer.

Proceedings of the Seminar on the Effective Utilisation and Management of Research Reactors. (1983). In *Presented at the seminar on the effective utilisation and management of research reactors*. Kuala Lumpur: Unit Tenaga Nuclear, Prime Minister's Department.

Proctor, R. N. (2008). Agnotology: A missing term to describe the cultural production of ignorance (and its study). In R. N. Proctor, & L. L. Schiebinger (Eds.), *Agnotology: The making and unmaking of ignorance*. Stanford, CA: Stanford University Press.

Program Sains Nuklear. (n.d.). Retrieved May 29, 2016, from http://sainsnuklear-ukm.blogspot.my/2015/05/history-v-1971-radiochemistryradiobiolo.html.

Puspati. (1981). *Laporan tahunan puspati 1981* (Annual Report No. PPA/AR/2)

Rashid, N. K. (1982). The design and construction of an electronic model of the chain reaction process. *Jernal Sains Nuklear/Nuclear Science Journal, 1*(1), 5-10.

Rashid, & Khair, N. (1984). The design and construction of a quiz board. *Jurnal Nuklear Sains/Nuclear Science Journal, 2*(1), 79-83.

Reinhardt, C. (2011). Expertise in methods, methods of expertise. In A. Nordmann, & M. Carrier (Eds.), *Science in the context of application* (pp. 143-159). Dordrecht: Springer Science +Business Media, B.V.

Rukun Negara. (2004, August 4). *Guiding or forgotten principles?*. Utusan Online. Retrieved from http://ww1.utusan.com.my/utusan/info.asp?y=2004&dt=0804&pub=Utusan_Express&sec=Features&pg=fe_03.htm.

Rukunegara (1970). Retrieved October 19, 2016, from http://epu.gov.my/sites/default/files/Rukunegara.pdf.

de Silva, L. (1970). *Development aid: A guide to facts and issues*. Geneva: Third World Forum in cooperation with the United Nations Non-Governmental Liaison Service (Geneva).

S'pore Bid for A-plant. (1955, October 22). *The straits times*.

Tan, B. T. G., & Ong, P. P. (1976). In *Proceedings of the Institute of physics Symposium*. Nanyang University Singapore: Institute of Physics.

Teller, E. (1977). *Nuclear energy in the developing World: Lectures by Dr Edward teller*. McLean, VA: Mitre Corporation.

The Association of Southeast Asian Institutions of Higher Learning. (n.d.). Retrieved October 22, 2016, from http://www.seameo.org/asaihl/.

The Text of the Agreement of 22 September 1980. (1981, February). *Concerning the Agency's assistance to Malaysia for the establishment of a research reactor project*. International Atomic Energy Agency. Retrieved from https://www.iaea.org/sites/default/files/infcirc287.pdf.

Training in Nuclear Know-How for Workers. (1981, november 18). *The straits times*.

Unit Teknologi Nuklear. (n.d.). Hubungan Kerjasama Teknikal Antara Unit Tenaga Nuklear dengan Jepun (No. PPA/PR/26). Bangi, Selangor.

Unit Tenaga Nuklear. (1989). *Annual report*. Kajang, Selangor: Tun Ismail Atomic Research Centre (PUSPATI).

Unit Tenaga Nuklear. (1990). *Laporan Kemajuan Program Penyelidikan IRPA di Bawah Rancangan Malaysia Ke-lima (1986-1990)*. Unit Tenaga Nuklear (No. PPA/PR/28 no. 1)

United States Atomic Energy Commission. (1958). *Geneva 1958: A report by the United States delegation to the second united nations international conference on the peaceful uses of atomic energy*. Geneva, Switzerland: Atoms for Peace.

United States Department of State. (1987). *IAEA technical assistance funding; the role of the IAEA in nuclear nonproliferation and nuclear safety; committee on assurances of supply (CAS)* (No. 88—DOS01310—LC). Retrieved from http://search.proquest.com/docview/1679140203?accountid=10598.

Weisberg, M. (2013). *Simulation and Similarity: Using models to understand the world*. Oxford & New York: Oxford University Press.

White, N. J. (2004). *British business in postcolonial Malaysia, 1957-1970: "Neo-colonialism" or "disengagement."* London & New York: Routledge-Curzon, Taylor and Francis Group.

York, H. (1976). *The Advisors: Oppenheimer, teller, and the superbomb*. San Francisco, CA: W.H. Freeman & Co.

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