ORGANIZATIONAL RESPONSES TO TECHNOLOGICAL DISCONTINUITIES: THE CASE OF THE AMERICAN COLLEGE OF RADIOLOGY (ACR)

BY

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DISSERTATION

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ABSTRACT

A long history of organizational research has shown that organizations are affected significantly by changes in technology. Scholars have given particular attention to the effects of so-called disruptive or discontinuous technological changes. Studies have repeatedly shown that established, incumbent organizations tend to suffer deep performance declines (and even complete demise) in the face of such changes, and researchers have devoted much attention to identifying the organizational conditions and processes that are responsible for this persistent and widespread pattern of adaptation failure. This dissertation, which examines the response of the American College of Radiology (ACR) to the emergence of nuclear magnetic resonance imaging technology (NMR), aims to contribute to this well-established research tradition in three distinct and important ways. First, it focuses on a fundamentally different type of organization, a professional association, rather than the technology producers examined in most prior research. Although technologies are well known to be embedded in "communities" that include technology producers, suppliers, customers, governmental entities, professional societies, and other entities, most prior research has focused on the responses and ultimate fate of producers alone. Little if any research has explored the responses of professional organizations in particular. Second, the study employs a sophisticated process methodology that identifies the individual *events* that make up the organization's response to technological change, as well as the overall *sequence* through which these events unfold. This process approach contrasts sharply with the variance models used in most previous studies and offers the promise of developing knowledge about how adaptation ultimately unfolds (or fails to). Finally, the project also contributes significantly through its exploration of an apparently *successful* case of adaptation to technological change. Though nuclear magnetic resonance imaging posed a serious threat to the ACR and its members, this threat appears to have been successfully managed and overcome.

Although the unique nature of the organization and the technology under study place some important limits on the generalizablity of this research, its findings nonetheless provide some important basic insights about the process through which social organizations can successfully adapt to discontinuous technological changes. These insights, which may also be of substantial relevance to technology producer organizations, will also be elaborated.

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CHAPTER I: INTRODUCTION

Nowadays, it seems rare when a single day goes by in which we do not hear or read about a new technology (i.e., the iPad) that will change our lives. Over time, some of us have grown less open to buy into the hype. However, for people of my generation (those born before 1970), technological change has been a big part of our lives. From PC computers, to satellite TV, to CDs, to cellular phones and iPods, technology has changed almost constantly—replacing old ways of doing things. Along with this modernization, though, we have experienced firsthand some of the less glamorous effects of these changes. Amy Glasmeier describes an example of this change in the emergence of key technological innovations in electronics and micromechanics on Switzerland's watch industry:

> "On the eve of the electronics revolution, the Swiss watch production system, centered in the […] Jura region was flexible, cost effective, and extremely profitable […] "the multiplicity of enterprises, and the competition and emulation that characterized the industry, yielded a product of superior quality known to the world over for high fashion, design and precision."(Landes, 1984: 48) Beginning in the 1970s when foreign competition hurdled technological frontiers […], the Jura's undisputed dominance ended. ***Massive job loss and out-immigration occurred as firms, unable or unwilling to adapt to new technologies closed their doors***. Today, […] Swiss watchmakers produce only a fraction of their pre-1970s output levels, and resources needed to invest in new product research and development are scarce." (Glasmeier, 1991: 469 empahis added)

Although not necessarily the outcome of all technological changes, this example depicts a case where the consequences suffered by organizations (its members and even the whole country's economy) unable to adapt to technological changes is severe. Perhaps for this reason, within organizational studies, a fair amount of resources has been dedicated to study technologies, how they evolve, and especially how they affect organizations. Empirical evidence has shown a strong link between technological and organizational changes (Christensen, 1997; Laurila, 1998; Rosenbloom & Christensen, 1998; Rothaermel & Hill, 2005; Sull, 1999; Tripsas, 1997).

A coherent set of investigations published by Michael Tushman and colleagues has uncovered how evolution in technology is connected to the organizations in which these technologies are embedded (Rosenkopf & Nerkar, 1999; Rosenkopf & Tushman, 1994; Rosenkopf & Tushman, 1998a; Rosenkopf & Tushman, 1998b; Tushman & Anderson, 1986; Tushman & Murmann, 1998; Tushman, Newman, & Romanelli, 1986; Tushman & Rosenkopf, 1992). This framework stresses that technological changes following a variation-selection-retention cycle are highly influenced by specific actors within a community of organizations. This community of organizations is a group of closely interrelated entities, including "competing organizations, professional societies, suppliers, customers, and governmental units"(Tushman & Rosenkopf, 1992: 343). Within this technological community, organizations are affected deeply by changes in evolving technologies, but they also play a key role in influencing the process of technological evolution. This strong relationship between the community of organizations and the evolution of technologies is also echoed in other conceptual and empirical works. For instance, Van de Ven and colleagues (Garud & Rappa, 1994; Garud & Van de Ven, 1989; Van de Ven, 1993; Van de Ven & Garud, 1989, 1994; Van de Ven & Grazman, 1999) stressed the importance of an augmented view of an industry (i.e., a community) when studying the creative destruction of with changes that go beyond a mere incremental advance in technology. Taken together, Tushman's and Van de Ven's frameworks offer a conceptualization in which technological changes significantly affect and are steered by the community of organizations in which these technologies are embedded.

If one is particularly interested in understanding how organizations within a technological community respond to technological changes—especially those considered radical, discontinuous, or competence destroying (Ehrnberg, 1995; Garcia & Calantone, 2002) —a complementary research stream has to be explored (see Chesbrough, 2001 for a literature review). This research stream, however, has focused only on one type of the community actors: the incumbent technology producer, offering a dim picture of their ability to respond effectively to technological discontinuities, in most cases, stressing inertial tendencies. At least two overarching arguments can be identified within this research stream. A first group of studies argues that producers are unable to adapt because they do not engage in explorative innovation, with some studies identifying as the inertial drivers managerial cognitive schemas (Kaplan, Murray, & Henderson, 2003), while others highlight structured routines as the main hindering forces to the attainment of new knowledge necessary for radical innovation (Leonard-Barton, 1992). A second group of studies suggests that incumbents can and do engage in explorative innovation, but they fail to commercialize those innovations. Again, different investigators have stressed different drivers for this phenomenon, some linking it to the lack of control over complementary assets (Mitchell, 1995), while others highlight as the main inertial driver the opposition of politically entrenched managers (Preece & Laurila, 2003). Other researchers within this stream have identified as the main inertial drivers the inability of firms to break commitments with key stakeholders (Christensen, 1993; Christensen & Bower, 1996; Sull, Tedlow, & Rosenbloom, 1997).

However, this previous research only provides insights for understanding the responses of producers to technological changes. How do other types of organizations within the technological community respond? Do they respond in the same way (struggling to respond effectively to the conditions created by a new, disruptive technology? These unanswered questions related to all the other organizations within the community reveal certain limitations within the literature reviewed.

It is known, however, that other members of the technological community are also central to the process of technological evolution. Different investigators have identified as influential actors during processes of technological change to users (Oudshoorn & Pinch, 2003), government agencies (Leonardi, 2010), and other members of the technological community where these technologies are embedded. If these organizations influence the evolution of their embedded technologies, it seems logical to expect that they are affected by changes in these core technologies, and have to respond somehow to these new technologies.

In particular, previous research on the creation of new industries triggered by disruptive technologies seems to hint that professional organizations can be one of these influential entities during technological change. Professional associations may influence community processes because they tend to play the role of legitimacy granting bodies (Hirsch, 1975), or act as expertise controllers (Abbott, 1988). These arguments can be interpreted as evidence that professional organizations can be influential during technological changes and, in turn, may need to find ways to respond effectively to the changes in technologies. That is why—in an effort to complement past research on technology and organizations—this research seeks to gain a deeper understanding of ***how and why a professional organization effectively responded to a specific technological discontinuity***.

Gaining insights on how other organizations within the community coped with technological changes seems a valuable effort. Additionally, focusing on an alternative organization's response to a technological discontinuity may complement previous research in at least four ways. First, gaining further understanding on how organizations respond to technological discontinuities can uncover the influence that actors may have on the dynamics and outcomes of the technological evolution process. Second, knowing more about how alternative organizations are able to respond effectively to specific disruptive technological changes can bring insights that could be transferred to technology producers coping with these technological jolts. Third, focusing on effective organizational response would help to balance the current heavy emphasis of the literature on inertial forces over continuity and adaptation efforts. Finally, choosing to tackle a "how" question would help by offering an alternative focus on "what" questions and by allowing me to contribute to this literature by using an alternative methodology: the process-centered approach (Van de Ven & Poole, 2005).

This approach to the study of a change process seeks to capture the richness and unpredictable occurrences that commonly take place in actual processes. From the construction of a timeline to the identification of special circumstances that created unexpected outcomes, the guiding assumption in the reconstruction of the process is that any entity's current state ought to be understood in terms of the history of events that preceded it (Abbott, 1983, 1995; Abell, 1987; Poole, Van de Ven, Dooley, & Holmes, 2000). This approach, then, has the advantage of allowing researchers "not only to support causal inferences, but also […] to trace the mediating steps through which causes act"(Poole *et al.*, 2000: 13). The advantages of this approach are, first, the exploration of "continuous and discontinuous causation, critical incidents, contextual effects and effects of formative patterns" (Poole *et al.*, 2000: 4). Second, this methodology has the ability to unveil the generative mechanisms, the "fundamental motors" (Van de Ven & Poole, 1995) explaining a specific change process. Finally, instead of selecting a potentially misleading level of analysis, this approach chooses the analysis of the event, the minimal expression of any process (Poole *et al.*, 2000).

With the research questions defined, the next step is to find a context in which to explore them. However, choosing an appropriate context to study the organizational responses to technological changes could be a thorny endeavor. The main problem in choosing a context is that technological discontinuities are events that can only be defined “a posteriori” and therefore one ought to do it retrospectively, relying heavily on archival documents, documents that only recounts what happened as the processes unfolded from the viewpoint of one actor. Considering this limitation, I tried to choose a relatively recent technological discontinuity that unfolded in the United States (the country where I resided during the extent of this project). After reading extensively, I found an example matching this criterion. This discontinuity was substantial and unraveled mainly in the United States, with consequent significant coverage of academic and nonacademic works focused on its development. This discontinuity was the emergence of nuclear magnetic resonance (NMR) devices, a jolt that had the potential to change profoundly the diagnostic medical imaging community.

In understanding this potential, it is important to note that nuclear magnetic resonance (NMR) devices emerged from a scientific field that was completely dissociated from X-ray technologies (the main knowledge base of the diagnostic medical imaging community). A central organization within this technological community was a professional organization: the American College of Radiology (ACR). Considering that radiology as a profession was linked particularly tightly to the the use of x-ray technology, any change in this central technological base was likely to be a significant event from the viewpoint of radiologists and, thus, the ACR. In other words, a disruptive technological change that rests on completely different physical principles and competences is likely to threaten the professional identity of radiologists, and thus, threaten the very identity of the ACR. This threat was so apparent and significant that a few key members of the community and some of the creators of this new technology noted that NMR stood for “No-More-Radiologists” (Blume, 1992).

Considering the theoretical insights coming from the empirical investigations aforementioned, one would expect that the ACR faced an extremely difficult challenge when adapting to the emergence of NMR devices. However, the ACR not only adapted and survived this disruptive technological change; seemingly, it even gained new prominence after the process completely unfolded (Linton, 1997). The question that remains is how the ACR dealt with this seemingly insurmountable challenge. The theoretical arguments summarized above do not help us completely to address this question. Hence, the primary objective of this dissertation is contributing to the technology and organizations research literature by delving specifically into the details of ***how and why the ACR coped with the challenges associated with the emergence of NMR***.

This project explores a "how" question and thus develops a process model of effective response to technological changes. This approach is unique within this literature because most previous investigations have focused on "what" questions and on developing insights into specific characteristics or organizational variables that explain certain behaviors of the firms under study. Second, this investigation contributes to the overarching organizational study literature by using a process-centered approach, a research methodology that has not been used much when studying specific organizational responses to technological discontinuities. Finally, this project also contributes to the literature on adaptation and inertia of organizations facing technological discontinuities by offering insights from an organization's effective response to technological changes. This is not a minor contribution either, because most of the previous investigations within this stream have portrayed inertial forces as almost inescapable and, therefore, successful adaptation as an unattainable objective for these entities. Balancing the evidence, toward effective change as less unlikely, could be an important step in the right direction.

However, in addition to these general contributions to the organizations and technology literature, the theoretical framework developed from the evidence also adds specific theoretical contributions. First, it exposes a highly adaptive entity that scanned the environment and took a wide variety of actions to ensure that the new technology would not negatively affect the organization itself, as well as its main constituents, the radiologists. The process unveiled by this framework is driven by a teleological motor, with the ACR actively shaping the sense-making process of its members and many of the other organizations participating in the technological community in which diagnostic imaging devices were embedded.

Second, this model can have at least two potential implications for the commonly studied producers of technology. First, if one accepts that professional associations may be influential actors during technological change processes, it would be convenient for producers of technology to associate themselves with these types of organizations or at least to observe their actions in order to predict or react to changes in policies, practices, or institutions generated by these organizations. Producers would be well advised in trying to proactively participate in the process of technological evolution, rather than only trying to produce the best technical or value proposition through their design or architectural choices. The model uncovered here stressed the importance of institutional, rather than technical or economical competence when succeeding in response to technological changes.

Third, the framework developed in this project highlights the effectiveness of the normalization efforts led by the ACR—in terms of not only crafting and re-crafting of community-wide cognitive schemas, but also in terms of policies and the practice of medicine associated with the new devices. This ability of the ACR to reshape institutionally-infused categories could open up a new set of questions in the research stream, given that, until now, few scholars have questioned the power of categories. The uncontested power of categories is demonstrated partially by the success of a set of investigations that portrayed changes in categories as almost impossible, and the main force behind unsuccessful adaptive efforts (Hannan, Baron, Hsu, & Koçak, 2006; Hannan, Pólos, & Carroll, 2003; Hsu & Hannan, 2005; Zuckerman, 1999; Zuckerman & Kim, 2003).

Finally, the theoretical framework developed here shows that entities that effectively respond to the emergence of disruptive technology did so not by merely responding to the challenge but rather by proactively influencing the process—and even the evolution of the artifact itself. This could reinvigorate works trying to unveil how other community organizations can influence technological trajectories. This suggests that not only specific (powerful, first-movers) producers or groups of producers are influential in how a technology evolves.

Empirical and conceptual bases of these contributions are discussed in detail in the following chapters. Indeed, chapter 2 provides a literature review in which theoretical arguments on technological evolution and organizational responses to them are defined. Chapter 2 specifically summarizes conceptual frameworks for understanding technologies, their evolution, and their interdependence with the fate of the organizations in which they are embedded. I also review the literature on organizational responses to technological changes (evolution) and how the research questions of this investigation are positioned vis-à-vis this research stream. I close chapter 2 by justifying the context chosen to explore these research questions.

Chapter 3 focuses on the empirical context chosen—the diagnostic medical imaging device community—explicitly recounting its history and evolution. A particularly detailed description of the multiple technologies embedded in this community since its inception is presented, from X-ray devices to CT scans. This historical recount seems necessary to allow for a deeper understanding of the changes that the emergence of the NMR devices had in this community. I finish chapter 3 reviewing the complete history of the central organization under study: the American College of Radiology. All these historical accounts are especially important for this investigation because one of the key tenants of the methodology chosen is its heavy reliance on how the history of entities influences their current actions.

Chapter 4 justifies and describes the methodology chosen, the process-centered approach, as well as the specific decisions made during the gathering of data on the ACR during the period under study. Additionally, I reviewed all the sources used to collect the data and present a brief description of the raw data gathered (i.e., incidents).

Chapter 5 is divided in two parts. The first part shows a historical reconstruction of the emergence, development, and eventual commercialization of the disruptive technology at the center of this investigation: the NMR devices. The second part depicts the data analysis, how I navigated through the different stages of evaluation of data, and the theoretical model derived from them. This model represents a conceptual contribution that seeks to provide details on how the effective response of the ACR to the emergence of NMR devices can be understood and why this organization was able to effectively cope with a technological jolt.

Finally, chapter 6 covers the direct conclusions of the conceptual model, explaining what this case reveals about how professional organizations respond to technological changes. I also discuss the lessons that can be transferred to other types of organizations within the technological community—specifically, technology producers. Also, I explore the potential consequences for the technological evolution literature as well as for the whole field of organizational studies. I close this chapter by detailing the limitations of this study and potential avenues for future research based on the insights developed by this investigation.

CHAPTER II: ORGANIZATIONAL RESPONSES TO TECHNOLOGICAL CHANGE

Seeking to understand how organizations respond to a particular type of technological change is certainly not a new endeavor within organizational studies. In fact, from the inception of this scientific field, technologies and their effects on organizations has been a central concern for organizational scholars (Thompson & Bates, 1957)[1]. This strong link between technology and organizations can be traced to the early conceptualizations of organizations. In these early arguments, which were focused on organizations as important social actors, all organizations were said to exist to "do some work" and that work was assumed to be done by using some technology possessed by these organizations (Scott, 2003: 22). Some scholars (Blau, McHugh-Falbe, McKinley, & Phelps, 1976; Tushman & Anderson, 1986; Tushman & Murmann, 1998; Tushman & Smith, 2002) interpreted this conceptualization of technology by focusing on technology as hardware; that is, as the equipment that "humans use in productive activities" (Orlikowski, 1992: 399). In contrast, others have interpreted technology as specific arrangements of tools, people, and tasks (Eveland, 1986; Galbraith, 1973; Thompson, 1967; Woodward, 1958). Others, drawing from a completely different ontological base, have argued that technology is a social product that cannot be studied separately from the social actors that use and give meaning to it (Barley, 1986; Bijker, 1987; Bijker & Law, 1992; Burrawoy, 1985; Pinch & Bijker, 1987; Wynne, 1988; Yoxen, 1987).[2]

Regardless of the particular conceptualization of technology, a myriad of investigations have consistently shown how influential technologies are for organizations (Barley, 1988; Dewett & Jones, 2001; Huber, 1990; Hulin & Roznowski, 1985; Orlikowski & Scott, 2008; Roberts & Grabowski, 1996; Zammuto, Griffith, Majchrzak, Dougherty, & Faraj, 2007). Perhaps more importantly for this particular investigation, empirical evidence shows a strong link between technological and organizational changes (Chesbrough, 1999; Christensen, 1997; Kaplan & Tripsas, 2008a; Laurila, 1998; Murmann, 2003; Rosenbloom & Christensen, 1998; Rothaermel & Hill, 2005; Tripsas, 1997; Tushman & Smith, 2002; Tushman, Smith, Wood, Westerman, & O'Reilly, 2002). Taken together, these previous ideas seem to stress the importance of clarifying how technologies evolve as the first step in investigating how organizations respond to technological change. Thus, I review below the most common framework used within organizational studies to understand how technologies evolve, and how those changes in technologies affect organizations.

Tushman's Framework of Technological Evolution

Perhaps the most influential model of technological evolution within organizational studies is the one developed by Philip Anderson and Michael Tushman (Anderson & Tushman, 1990; Tushman & Anderson, 1986). This model conceptualizes technology in terms of its physical features (i.e., hardware) and posits that its evolution is tightly linked to a certain group of organizations (Rosenkopf & Nerkar, 1999; Rosenkopf & Tushman, 1994; Rosenkopf & Tushman, 1998a; Rosenkopf & Tushman, 1998b; Tushman & Murmann, 1998; Tushman et al., 1986; Tushman & O'Reilly, 1997; Tushman & Rosenkopf, 1992; Tushman & Smith, 2002; Tushman et al., 2002).

In this framework, technology (i.e., artifacts) evolves following a variation-selection-retention cycle. This model interprets previous historical accounts of the evolution of "nuclear reactors, cotton gins, barbed wire, […] rail-way propulsion systems, […] automatically controlled machine tools, […] electric power systems, […] radio systems, bicycles […], turbojet propulsion, […] numerical control machine tools" (Tushman and Murmann, 1998: 239) as unequivocally supporting this cyclical model. These authors note that the striking similarity of these examples is evidence that technological evolutionary processes are driven by a variation event that is later followed by a selection process, which leads to a continuity era. Starting anew the cycle, this period of continuity is broken eventually by a new variation event.

The cyclical evolutionary process offered by Tushman and colleagues is constituted then by four components: two significant events (i.e., technological discontinuities and selection of dominant designs) and two clearly distinguished eras or stages (i.e., era of ferment and era of incremental change) in which qualitative, different dynamics can be identified (see Figure 1). A succinct description of the components of this model follows.

(1) *Technological discontinuities* are "rare, unpredictable innovations which advance a relevant technological frontier by an order-of-magnitude which involve fundamentally different product or process design" (Tushman & Rosenkopf, 1992: 318). These events are especially important in this model because they serve as triggers of a qualitatively different type of interaction dynamics among the actors in the technological community (i.e., incremental vs. radical development of technologies and efficiency competence vs. effectiveness competence). These discontinuities, the model notes, can be of two types: competence-destroying (CDTD) and competence-enhancing (Ehrnberg, 1995; Gatignon, Tushman, Smith, & Anderson, 2002). The former consists of a discontinuity (Gatignon *et al.*, 2002: 1107) that "obsolesces and overturns existing competencies, skills and know-how." The critical issue for these type of discontinuities is that the new knowledge base turns previous mastering of the current technology obsolete (Tushman & Rosenkopf, 1992). Thus, it has a marked impact on the organizations that had been relying on those skills to survive and compete in that environment.

(2) *Eras of ferment* are started by the discontinuities described above. Tushman and colleagues identified two distinct processes during this period: (a) competition between old and new technological regimes and (b) competition within new technological regimes. A key to the first competitive process is that older technological orders do not vanish quietly (Tushman & Rosenkopf, 1992). Empirical evidence shows that existing communities often respond by increasing the "innovativeness and efficiency" of the existing technology as a

way of resisting the new technologies (Foster, 1986; Hughes, 1983; Postrel, 1990). On top of this competitive dynamic between new and old regimes, these scholars drew attention to how the competition dynamics within the new technological regime crystallize. Not only do competing technologies battle along functional dimensions of merit, but also, and perhaps more importantly, they do so *in defining which dimensions are important first*. These competitive wars over how to measure the performance of the new technology are not merely rhetorical, but, in fact, they are quite consequential for the final outcome of which technology is selected, given the high uncertainty that all community members face during these periods (Tushman & Rosenkopf, 1992).

(3) The *selection of a dominant design* is the second turning point in the cycle model. A dominant design is a truce or settlement in which a design becomes a de facto standard within the relevant technological community (Tushman & Murmann, 1998; Tushman & Rosenkopf, 1992). A current, refined model of this process of settlement resolved previous arguments in the literature by offering a nested hierarchy of technology cycles in which artifacts, the technology under study, are decomposed into subsystems and linking mechanisms (Murmann, 2003; Murmann & Tushman, 2001)[3]. Under this new perspective, the phenomenon of dominant design applies fundamentally at the "subsystem and linking levels of analysis" (Tushman & Murmann, 1998: 252). Beyond the precise elaboration regarding at what level of the evolving artifact the empirical evidence should be collected, a critical contribution of this research stream has been to bring the nature of the settlement to the forefront of the discussion. Indeed, these scholars uncovered that this truce event between community members is inherently a sociopolitical process rather than merely a technical or economic optimization choice. They emphasized that, in contrast to discontinuities, events that emerge stochastically, dominant designs emerge as a sole consequence of a "population-level compromise and accommodation." (Tushman & Murmann, 1998: 252) These scholars highlight the influence of two potential models in understanding this process of community compromise and accommodation (Tushman & Rosenkopf, 1992). In one model, they stress the importance of previous power structures within the community. These structures can sway the settlement through the role of a dominant actor—producer, supplier, customer, industry committee, alliance, or regulator. Under the second model, a concomitant evolution (what they coined "coevolution") of the new and old participants of the whole community at

the same time compels and is compelled by the technological change (Rosenkopf & Tushman, 1994; Rosenkopf & Tushman, 1998b).

(4) An *era of incremental change* starts as soon as a dominant design emerges. Dominant designs significantly reduce the uncertainty within the population, facilitating the relationships between the different actors and allowing system-wide compatibility and integration. Technical progress is driven now by several incremental innovations. These innovations involve "puzzle-solving about a given set of technological premises" (Tushman & Rosenkopf, 1992: 323). It seems especially important to highlight that a key argument offered by this research stream is that, during this era, the social structures within the technological communities tend to reinforce order-creating technical change; critical problems and procedures are shaped significantly by the norms; and values emerged from the interactions of the interdependent actors within the community. In sum, in contrast with the previous era in which the influence of the different actors is overt (a "visible hand"), during this era, the dynamics are dominated by "an invisible hand" of sharp technical, social, and normative constraints derived from the interactions of the technological community. It is exactly for this ossification process that "existing technical communities [...rarely] give birth to radically new competence-destroying technologies [..., and they are] resisted by technological, social and political processes as veteran organizations and communities defend the existing paradigm"(Tushman & Rosenkopf, 1992: 324/325).

Arguably, this model brought about three key contributions to the understanding of technological evolution and its relationship with organizations (O'Reilly & Tushman, forthcoming). First, it elaborated on the details of the competitive dynamics within each era of the cycle. That is, it illustrated that different events during this cycle have qualitatively different consequences in those organizations both influencing and being affected by this evolutionary process. Second, it underlined the role of specific actors within the technological community on the developments and outcomes of the evolutionary process. Finally, it stressed how consequential social and political processes are to the evolutionary cycle[4]. In sum, this framework provides a model of technological evolution in which technologies are embedded deeply in a given technological community of organizations. This community of organizations, as noted before, is a group of entities comprise of producers, professional societies, suppliers, customers, and regulators. Within this community, each of these entities are influenced deeply by the transformations in the evolving technologies, but, in turn, they can also affect the process of technological evolution. Another conceptual and empirical set of works highlight this strong link between communities and their embedded technologies. In particular, Van de Ven and colleagues noted (Garud & Van de Ven, 1989; Van de Ven, 1993; Van de Ven & Garud, 1989, 1994) that we need to enhance our view of industries if we want to assess all the players influencing the process by which extraordinary innovations are created. In particular, they emphasized the importance of actors such as those linked to institutional arrangements (governmental agencies, professional trade associations, and specific scientific/technical communities). Second, they highlight the role of actors linked to the necessary resource endowments to create these innovations, such as scientists, financiers, financial analysts, and so on. Third, they refer to the actors who use or buy the innovation (consumers), and, finally, to the actors transforming the innovations through proprietary activities (lawyers, business processes officers, etc.).

Taken together, these frameworks previously discussed focused on the understanding of the process of evolution of technologies present an imagery in which technological changes—especially those radical, disruptive, discontinuous, or CDTD (depending on which conceptualization one chooses to adopt)—significantly affect and are steered by the community of organizations in which these technologies are embedded. Thus, it seems logical to delve into the current understanding of how these particular technological changes affect particular organizations. That is the focus of the next subsection.

Technological Change and Organizational Responses

A large research stream has explored the way in which organizations respond to technological discontinuities (Chesbrough, 2001). Although there is a multitude of works coming from a plethora of angles, most of them focus on the specific responses of only one type of community actor: the incumbent technology producer.

Indeed, previous studies have offered a dim picture regarding the ability of technology producers to respond effectively to these discontinuities, in most cases, stressing inertial tendencies. At least two overarching arguments can be singled out from this stream. A first group of studies notes that incumbent producers are unable to adapt to technological discontinuities because they do not engage in explorative learning (by investing in radically new technologies). Some explain this learning deficit by noting that organizations rationally invest more in incremental innovations rather than in radical innovations because the latter might cannibalize their current products (Cohen, 1995; Henderson, 1993; Hill & Rothaermel, 2003). Other scholars highlight that incumbents fail to invest in radically new technology because they develop structured routines that seriously constrain their ability to acquire the new knowledge necessary for radical innovation (Leonard-Barton, 1992; March, 1991). Yet others argue that incumbents do not invest in radical innovations because decision makers become embedded in shared cognitive schema that prevent them from perceiving the need to engage in explorative activities (Abrahamson, 1991; Kaplan, forthcoming-a; Kaplan *et al.*, 2003; Tripsas & Gavetti, 2000).

A second group of studies suggests that incumbents can and do engage in explorative learning, even creating radically new technologies themselves. However, these studies suggest that incumbent firms are unable to commit themselves to the endeavor of implementing and commercializing such technologies. Several mechanisms are offered to explain these inertial tendencies. Some studies suggest that politically entrenched middle- and upper-level managers oppose or even sabotage new technologies that threaten to undermine their positions of power (Laurila, 1998; Laurrila & Preece, 2003; Preece & Laurila, 2003). Others claim that incumbents are unable to commit to new technologies because they are incapable of breaking commitments to existing customers and suppliers (Christensen & Bower, 1996; Christensen & Overdorf, 2000) or other firms' stakeholders (Sull, 1999; Sull *et al.*, 1997). Still other scholars have argued that the inability of some firms to implement and commercialize the new technology is rooted in the organizational identity of these incumbents (Flores, 2006; Tripsas, forthcoming). Finally, other scholars point out the lack of control that incumbents may have over complementary assets (especially those relating to the value chain connecting these firms with critical clients and suppliers) in the new technological regime (Mitchell, 1988, 1995; Rothaermel, 2001; Tripsas, 1997). Taken together, this research stream has brought multiple insights to our understanding of how organizations respond to technological discontinuities. However, these insights are focused singularly on producers of these technologies, as if this type of organization were the only one affected by these jolts, or the only one capable of shaping these evolutionary processes. Below, I explicitly address the apparent weakness of this research stream to position this investigation vis-à-vis the literature, focused on organizational responses to technological discontinuities.

Research Questions

Although most of the previous literature has focused on producers of the technologies under study, additional empirical evidence suggests that other members of the technological community are also central to the process of technological evolution. For instance, users (Coombs, Green, Richards, & Walsh, 2001; Oudshoorn & Pinch, 2003; Von Hippel, 1976), government agencies (Garud & Karnøe, 2003; Leonardi, 2010), security analysts (Benner, 2010), and, more generally, key financial actors linked to critical resources (Benner, 2008) have also been found to influence the process of technological evolution. Therefore, one can logically expect that each of these community actors could also be affected by technological discontinuities and thus, has to respond to it. How are these actors within the technological community affected by technological discontinuities? Do they respond in the same way as technology producers? These and other related questions linked to the specific actors within the evolving technological community reveal certain limitations within the literature reviewed. Taking seriously the idea that technologies can be affected by the actions of the members of the evolving community, it is logical to assume that professional societies, suppliers, and other actors within a specific technological community also face challenges responding to the technological changes, especially disruptive ones. Thus, students of technologies and organizations may also learn much from studying the specific responses of organizations confronting these changes, especially if these organizations are able to adapt to the disruption presented by this type of discontinuous technological change. Enhancing the current understanding of how other organizations within a community coped with technological changes seems a worthwhile endeavor. Knowing more about how these other organizations, as well as all the other community actors, can effectively cope with technological discontinuities is a valuable undertaking, because evidence shows that the demise of these organizations leads to large rounds of layoffs and other profound negative consequences for the organizations (Edwards, 2000; Kaplan, forthcoming-b; Song, 2009). In fact, in an extreme case, an inability to adapt could even imply the complete loss of the technological community (Glasmeier, 1991), and thus the loss of an entire sector or industry for a country (e.g., the replacement of the old Switzerland watch industry by a global network centered in Japan). Hence, gaining insights on how some organizations survive technological jolts could have even broader policy implications for those trying to create or preserve strategic industries in specific regions of their country.

Studying the responses of more than one of these community members, however, could be quite complex and even counterproductive, considering the limited knowledge accumulated about particular roles and actions for each distinctive type of organization. Thus, it seems logical to start this alternative research path by focusing on one type of organization within a technological community. Previous research on innovations and the emergence of new industries created by disruptive technologies seems to hint that one set of actors who can be quite influential during these processes are professional associations. Several investigations have uncovered that professionals are critically consequential actors during the emergence of a technological discontinuity. Because of their key role as legitimacy gatekeepers, they influence community processes when interacting with other community actors (Hirsch, 1975), and, during the emergence of new technologies, they play the role of opinion leaders, boundary spanners (Swan & Newell, 1995), and expertise holders (Abbott, 1988). All the previous evidence suggests that focusing on professional organizations that have responded effectively to technological discontinuities may be a meaningful path to take. That is why in trying to complement past research on technology and organizations, I specifically aim to contribute to this literature by seeking a deeper understanding of how and why some professional organizations effectively respond to technological discontinuities.

However, I would argue that focusing on professional associations' response to technological discontinuities might illuminate additional insights that could complement previous research on this issue. First, gaining further understanding on how these organizations respond to technological discontinuities could uncover the influence that these actors may have on the dynamics and outcomes of the technological evolution process. Indeed, this would address Tushman's call for more investigations on this topic when arguing that "we need to know more about how interactions between competing organizations, professional societies, suppliers, customers and governmental units shape technological evolution"(Tushman & Rosenkopf, 1992: 343). Second, enhancing our understanding of how these alternative organizations are able to respond effectively to specific disruptive technological changes can bring some insights into how technology producers could effectively cope with technological jolts. Third, focusing on effective organizational response would help to balance the heavy emphasis of the literature on inertial forces over continuity and adaptation efforts. Finally, choosing to tackle a "how" question would complement literature that so far has favored "what" questions (e.g., what organizational characteristics or variables explain organizational inertia during disruptive technological changes). With the leading research question and the positioning of this investigation detailed, the choice of the specific context in which this research question could be explored will be reviewed in the upcoming subsection.

Choosing a Context

Studying organizational responses to technological changes or, more generally, to technological evolution processes, is a thorny endeavor. The main problem is that technological discontinuities are events that can only be defined "a posteriori" (Tushman & Anderson, 1986). This implies that scholars interested in studying these phenomena must do it retrospectively, relying heavily on history and historical documents. Considering the key limitation of relying almost completely on historical recounts, I tried to focus on the emergence of major technological disruptions that had unfolded predominantly in the United States in the last few decades, assuming that more recent technological disruptions will allow for a better quality and quantity of information, thus reducing some of the key drawbacks of archival research. I foraged popular and academic publications detailing relatively recent technological disruptions that unfolded in the United States. After reading extensively about a variety of technological events, I finally found an example that fit the criteria I had previously set. The technological discontinuity I chose was substantial in terms of the disruption of community interactions, relatively recent (mainly unfolded during the 1980s), and unraveled mainly in the United States, with the consequent coverage of academic and nonacademic articles, but, more importantly, with key actors still operating (in the late 2000s).

The technological disruption that best fit these criteria was the emergence of nuclear magnetic resonance (NMR) devices. The creation and commercialization of NMR devices had the potential to profoundly change the diagnostic medical imaging community. First, nuclear magnetic resonance (NMR) devices emerged from a scientific field that was completely dissociated from X-ray technologies, on which the organizational competences of all the community actors rested (Kevles, 1997). Second, the skills needed to operate and interpret the results provided by these devices were completely different (morphology vs. physiology imaging) to those used by the most central professionals of this community: the radiologists (Blume, 1992; Joyce, 2008). Thus, the emergence of these new devices significantly threatened key “jurisdictional claims” (Abbott, 1988) of radiologists and the main knowledge base of most community members. Additionally, it became apparent that a central organization within this technological community was a professional organization: the American College of Radiology (ACR). This professional organization was the premier organization representing the radiologists, an influential professional group within the diagnostic medical imaging community (Barley, 1984, 1986; Linton, 1997). Considering that radiology, “unlike most medical specialties that developed as physicians concentrated on particular organ systems, patient populations, or diseases, […] grew up around the use [of x-ray technology]" (Barley, 1984: 19), any change in this technology base was likely critically threatening from the viewpoint of radiologists and, thus, the ACR.

As noted before, relying on the insights coming from the research reviewed here the fate of the ACR under these new technological circumstances would appear quite faint, likely being unable to respond effectively to such a disruptive technological transformation. Nevertheless, the ACR not only subsist and adapted to the emergence of NMR devices, but according to some accounts, the ACR even gained new prominence afterwards (Linton, 1997). How can one explain this effective response by the ACR even when faced with such a disruptive change? The theories aforementioned do not seem to provide satisfactory or complete answers to this question. Thus, the principal purpose of this thesis is complementing these previous investigations within the technology and organizations literature by uncovering how and why the ACR was able to respond effectively to the challenges linked to the emergence of NMR device. The next chapter extends this review of the context and central organization of this investigation by examining the diagnostic medical imaging community since its inception, the role that ACR played in the evolution of the community before the emergence of NMR devices.

CHAPTER III: THE DIAGNOSTIC MEDICAL IMAGING (1895–1975)

The U.S. health-care industry is an industrial sector that has relied markedly on the development and use of new technology (Scott, Ruef, Mendel, & Caronna, 2000). Technology has been so integral to this sector that it has been argued that U.S. physicians followed a “technological imperative,” a belief that doctors in every hospital “should have available for his patients all the technologies medicine, regardless of cost, […] priority, or […] optimal allocation of resources”(Bennett, 1977: 127). Providing evidence of this continuing strong relationship between technology and the health-care sector in the United States, Burns (2005: 3) notes “the cost of new technology and the intensity with which it is used, consistently accounts for 20 to 40 percent of the rise in the health care expenditures over the past forty years [1961-1997].” This sector has become so important that one could argue it has become a strategic sector in the whole economy of the country (Burns, 2005).

Within the health-care sector, medical devices are one of the most attractive divisions in terms of profitability, with revenues going from $16 billion in 1980 to $90 billion in 2003 (Kruger, 2005). Multiple studies have chosen this technological community as the specific context for their investigations. Studies have investigated different aspects of this community. Some investigations have offered a complete historical account of the evolution of the community (see for instance Blume, 1992 or ; Kevles, 1997)). Others have focused only on a particular period or technology, assessing the economics of manufacturing firms (McKay, 1984); uncovering the dynamics of commercialization, transference, and licensing (Mitchell, 1988, 1991); or identifying the determinants of success for newcomers and incumbents (Das & Van de Ven, 2000; Mitchell, 1995). Others have focused on how specific technologies (e.g., CT scans or NMR scans) affected specific community members (Barley, 1984, 1986, 1988; Kleinfield, 1985;

Mattson & Simon, 1996). However, none of these investigations within the medical device sector has directly focused on the ACR, neither as a key organization within this technological community nor as a potentially influential community actor. The next subsection presents a brief review of the history of this technological community from its inception to the emergence of NMR devices. This brief historical recount, focused on the key technologies embedded in this community, does not seek to provide a comprehensive account of the history of each member of this community, nor does it try to explain the emergence of previous technologies, as these issues have been discussed elsewhere brilliantly[5]. In contrast, the following subsection aims to provide the necessary context to appreciate how the emergence of NMR devices disrupted key relationships between particular actors and the diagnostic medical device imaging community as a whole.

The Inception: X-Ray Devices

As noted before, the diagnostic medical device imaging community has a long history that can be traced back to the discovery and use of the X-ray machine in the last years of the 19th century (Brecher & Brecher, 1969; Brown, 1936). Wilhelm Conrad Roentgen discovered X-rays on November 8, 1895, in the Physical Institute at the University of Würzburg (Brecher & Brecher, 1969). In fact, what Roentgen had discovered were rays invisible to the naked eye, but with the important property of leaving some imprint in photosensitized plates or film. When these rays encountered an object (commonly a part of the human body) that absorbed some of them, they would produce an imprint in those photosensitized plates or film. This imprint was termed the radiograph (Kevles, 1997). On developed film, denser areas, such as bone, appear white, whereas soft tissues emerge more darkly. Thus, radiographs, “shadowgrams,” or X-rays as they are commonly called, are actually records of tissue density (Barley, 1984). See Figures 2 and 3 to gain additional insights on the first X-ray machines and their corresponding radiographs.

In the United States, the pioneers replicating and expanding upon the discovery of Roentgen, as early as January of 1896, were Yale's investigator Arthur Williams Wright, and Harvard's John Trowbridge (Brecher & Brecher, 1969). A myriad of applications emerged from these early X-ray devices, so much so that by late 1896, there were already two commercial producers, one in Germany (Siemens AG) and one in the United States (General Electric) (Mitchell, 1988). In fact, it has been argued that X-rays significantly changed the world (Blume, 1992; Kevles, 1997), given their profound impact on multiple areas of human life—from scientists' interests to how humans understood their own privacy. The device had such a important impact that "only two months after X-rays had become public knowledge, they were accepted as evidence in court" (Kevles, 1997: 31).

However, in the middle of this overwhelming, general enthusiasm about the newly gained ability to see inside the human body, less welcome news was also beginning to emerge that noted that these new rays "do not merely pass through human tissue in the way the light passes through glass. Instead, they may produce undesirable changes in the tissues exposed to radiation" (Brecher & Brecher, 1969: 81). The cause of these problems was discovered much later. X-rays rely on ionizing radiation, and this kind of energy can cause burns, tumors, and genetic damage, especially on sensitive fetal or infantile tissues, or in the body of those individuals who work daily with the rays, because the radiation effects are cumulative (Mitchell, 1988).

By 1897, the first Roentgen society was created in the United Kingdom, while the American Roentgen Ray Society (ARRS) was organized a few years later in 1900. These organizations, grouping investigators regardless of their professional affiliation (i.e., physicists, engineers and physicians were members of these societies), were only interested, at least at the beginning of their existence, on further developing the knowledge and application of these new devices without really trying to influence particular medical applications or claiming particular expertise over these new devices (Barley, 1984). In the coming years, these investigations produced enough evidence to justify the effectiveness of this new technology to be applied in the common practice of medicine. However, considering that most physicians could not read radiographs, the individuals producing the images, engineers, physicists, and so forth, ended up interpreting or reading them (Barley, 1984).

X-rays were generated in the initial machines through a glass tube that contained two metal electrodes. Through the passage of electrical currents to one of the electrodes (the cathode), the difference in electrical potential between these two surfaces increased until it reached a point when a discharge (or stream of electrons) occurred from the cathode to the other electrode (the anode). When the electrons strike the anode, X-rays are produced (Mitchell, 1988). That is why these early devices were known as "gas tubes" (though not completely vacated of air), and the years between 1896 and 1913 came to be known as the gas-tube era (Brecher & Brecher, 1969). This era was significant because a new group of individuals would gain a considerable influence in the manipulation and medical use of these devices.

> "Among the major advances of the gas-tube era was the emergence of a new scientific breed-a small but influential group of physicians, well-versed in the physics of radiation as well as in medical practice, who called themselves 'radiologists' or 'roentgenolists', and who raised the use of the X-ray for diagnosis and for the therapy to the status of a new medical specialty." (Brecher & Brecher, 1969: 103)

During this period, the use of this new equipment focused on broken bones and on the localization of foreign objects wedged into the body. With the gradual improvement of the equipment came a gradual broadening of the usage of X-rays. Indeed, this era was the golden era of the "retro-spectroscopy." Through retro-spectroscopy radiologists refined their interpretations of particular radiographs by retrospectively assessing their interpretations with the actual problem uncovered by a surgery or an autopsy. Accumulating these lessons allowed radiologists to expand the use of these devices to multiple situations, from examining the brain, to diagnosing the gastrointestinal tract, to treating skin tuberculosis (Brecher & Brecher, 1969).

As the radiologists learned new uses and increased their effectiveness in interpreting the shadowgrams, the equipment incrementally improved. Indeed, in December of 1913, a significant improvement allowed radiologists to do new things and do "old" things better with a new generation of X-ray machines. These new devices created by Dr. Coolidge were equipped with a tube that had a pressure "as low as it has been possible […and] it emitted far more X-rays […] by using a hot-cathode, tungsten-target tube" (Brecher & Brecher, 1969: 196). These improved devices were coined as "the most important contribution to Roentgenlogy since the birth of that science," given their increasing accuracy of adjustment, stability, exact duplication of previous results, the flexibility of the tube, and higher output (Brecher & Brecher, 1969: 197). These improvements attracted many additional physicians to radiology. Equipped with the Coolidge tube and other technological improvements (such as the Potter-Bucky diaphragm, stable and abundant power supplies, fast and convenient film, and an increasing supply of radium), "radiology after 1920 entered a period of rapid development" (Brecher & Brecher, 1969: 211). During the next several decades, the radiographs improved consistently as evolution in the devices compounded. Better tubes, full-wave rectification methods that reduced imaging times, equipment to focus the radiation, and better film all continued to improve the basic X-ray devices, maintaining the main principles of use, interpretation, and actors involved and creating and sustaining the base for the diagnostic imaging device community.

By 1940, another significant technological change was introduced: by changing how X-rays were visualized. The changes allowed the new devices to have a monitor that could display an image that was several times brighter than the original fluoroscopy picture, allowing some reduction on the intensity of X-rays (Mitchell, 1988). By the end of 1950s, the X-ray devices had become standardized, and product advancements were largely incremental (Mitchell, 1988). See Figure 4 (a & b) to compare the original X-ray devices with newer ones, as well as Figure 4 (c & d) for a similar comparison of the radiograph's evolution.

The manufacturers of these devices increased from the inception of the field to the late 1950s from a few electric-machinery companies to almost twenty key players, even though the same major firms (GE and Siemens) still dominated the market (Mitchell, 1988). Other key players in this technological community were companies providing film (Kodak), some governmental agencies such as the National Institutes of Health (NIH) and the National Cancer Institute (NCI), which influence the community mainly through the funding for research on safety in the use of the devices. However, the end of the 1950s would bring two new technologies that would significantly affect the community. A review of these change-inducing technologies follows.

A Different "Ray": The Nuclear Medical Devices (Gamma Cameras, SPECT, & PET)

As researchers and physicians learned more about the human body, they also started wondering whether other electromagnetic rays could be used to explore inside the body. One of these applications of a different type of electromagnetic wave was the base for a set of applications known as *nuclear medical devices*. These devices involve administering a small amount of gamma rays emitting radioactive substance to a patient. A detector later collected and recorded the pattern of the photons that were emitted by this substance (Mitchell, 1988). A specialist later interpreted this information. This technology uses specific, small, nontoxic substances that accumulate in organs or systems to produce static or dynamic images of the system under study. A key advantage of this technique is that it goes beyond morphology, which was the key output achieved by X-ray shadowgraphs, because it gives physicians a window to the biological function of specific organs. Additionally, because it requires lower levels of ionizing radiation, it is safer than conventional X-ray methods (Mitchell, 1988). Unfortunately, the spatial resolution of the images is generally poor, so the use of these devices has been limited.

The emergence of this technology was a direct consequence of World War II and the research that the United States and other countries initiated during and after this conflict. The main instruments that emerged in the late 1940s and early 1950s were focused on studying human metabolism and brain tumors. Beyond those used to study tissue samples, in-vivo equipment was developed during the mid- to late-1950s (Mitchell, 1988). Around the same time, radioactive substances were developed in government-sponsored laboratories(Mitchell, 1988). By the late 1950s, Brookhaven National Laboratory had developed a radioactive substance known as Technetium-99m, which had a low radiation level and a simple decay scheme that would allow it to be used in the whole body with minimum quantities (Mitchell, 1988).

During this period, two concomitant research efforts were underway. One group of investigators, who worked mainly at universities, tried to produce stationary detectors, or cameras, of the photon emitted by these radioactive substances. Others—predominantly key members of the medical device imaging community—focused on larger devices known as rectilinear scanners. By 1957, university researchers were able to produce a prototype of this camera, but, considering that an image took an hour to be produced, the device was considered clinically ineffective (Mitchell, 1988). However, Nuclear Chicago Corporation used the lessons learned from this prototype, and a few years later the firm developed a commercial instrument (see Figure 5-a) that was first placed at Ohio State University in 1962 (Mitchell, 1988). By 1959, Picker, a leader in the X-ray device manufacturing and commercialization, introduced the first nuclear rectilinear scanner. The emergence of these new devices not only gave physicians new ways of exploring inside the human body, but also brought new actors to the diagnostic imaging device community. These new actors included not only the companies manufacturing these new devices, but also new physicians who were interested in using and interpreting these images, and new governmental agencies regulating the use of these devices and the chemical substances associated with them (e.g., the Atomic Energy Commission (AEC) and the Nuclear Regulatory Commission (NRC)). Figure 5-b shows a newer model of the gamma camera. It is important to see the differences between the images produced with this technology compared to the ones produced with X-ray devices. Figure 6-a illustrates a typical image, in this case, a heart study, produced by the original gamma cameras. Figure 6-b shows a set of images produced with the newer models of this technology.

However, the technological advancements did not soon stop. Indeed, other investigators introduced even more innovative devices soon after by incorporating “computers” to these machines. The computers functioned to code the intensity and location of the photons captured from the radioactive substances in the organ under study, creating enhanced images. This new calculation power within the imaging devices would open the medical community to a completely new concept: a tomogram, or slice image[6]. Computers, through their calculation power, allowed these devices to “reconstruct” images by superposing and recalculating the radiations detected from several angles (Mitchell, 1988). From these developments, two types of nuclear medical devices emerged: the single photon emission computed tomography (SPECT) and the positron emission tomography (PET).

Single photon emission computed tomography (SPECT) devices use conventional radionuclide, such as Technetium-99m (Mitchell, 1988). The photons that are emitted by this radionuclide are identified by an array of detectors that rotate around the body, incrementally collecting images of the body. The images are then processed by a computer that creates the slides programmed by the operator (Mitchell, 1988). Baird and Searle were leaders in commercializing these devices. In contrast to SPECT devices, positron emission tomography (PET) devices create images based on imaging of positrons. Positrons are antiparticles of electrons, with their same mass. While radioactive decaying, "positrons are emitted from the nucleus of some atoms along with protons and neutrons […they] travel a short distance and collides almost instantly with an electron. They annihilate each other, and in the process produce two photons or gamma rays, that shoot off at 180-degree angles from each other" (Kevles, 1997: 204). PET devices take advantage of this phenomenon by locating a ring of electronic detectors around the radioactively inoculated body under study. Whenever two detectors at opposite sides of the ring are hit by photons at the same time, one could infer that a positron must have been emitted from inside the body. Using some spatial mathematics (mainly derived from the co-evolving CT devices), the computer inside the device recreates an image of the spatial density of the area where the radioisotopes are located inside the body (Kevles, 1997). This process was described in a scientific paper published by the investigators Phelps and Ter-Pegossian in 1975. By mid-1980s "the hardware of PET scanners and radiopharmaceutical manufacturing had reached a stage where the emphasis shifted from invention to fine-tuning" (Kevles, 1997: 210).

In contrast with the previous technologies, in which the incumbent manufacturers' involvement and leadership was critical, nuclear medicine devices (especially PET) were "funded, organized, encouraged and distributed by the U.S. government" (Kevles, 1997: 211). The economics of these devices was always uncertain, and even the Health Care Finance Administration (HCFA), through its programs (Medicare and Medicaid), didn't cover any PET procedures until 1995 (Kevles, 1997). The AEC funded most of the research on radioactive pharmaceuticals in a myriad of laboratories across the country. The National Institutes of Health (NIH) also offered research grants on the clinical application of these devices, but later the Department of Energy facilitated the transfer of this technology to the diagnostic medical imaging industry—mainly to the incumbent manufacturers (Kevles, 1997).

In addition to the close monitoring and facilitation of these devices by the government, their own emergence significantly influenced key actors in the community. In fact, a new group gained relevance, considering the unique nature and scientific base of these new devices. These new actors formed an association called the Society of Nuclear Medicine in 1954, a group officially recognized as a medical specialty by the American Medical Association in 1971. This new professional group would be critical in the use and development of these new devices. A concomitant evolving technology that would also significantly affect the diagnostic imaging device community is detailed below.

From Sound to Images: The Ultrasound Imaging Devices

Although diagnostic imaging devices based on mechanical vibrations at frequencies above the range of human hearing were being explored in the mid-1940s, it was not until the mid-1960s that imaging device manufacturers tried to commercialize these types of instruments to clinical users. Manufacturers developed two types of mechanical vibration devices. The first type, the Doppler wave instrumentation, produces an ultrasonic wave that elicits a measurable frequency change when it is echoed by a moving object (Mitchell, 1988). This change in frequency was commonly used to measure blood flow or to monitor fetal heartbeat, because the early Doppler-based instrumentations did not produce images (Mitchell, 1988). In contrast, pulse-echo equipment (composed commonly of a transducer, a transmitter, a receiver, a signal amplifier, and a cathode-ray tube monitor) uses a sonar-like mode to produce images. When the transducer is placed in contact with the skin, about 500 pulses per second enter the tissue under it, and the underlying organs later reflect these pulses (Mitchell, 1988). The time and strength of the echo provide information that can be used to reproduce an image of the underlying organs on a cathode-ray tube (Mitchell, 1988). These devices have many advantages over X-ray machines or nuclear medical devices, because they do not use ionizing radiation, and the type and quantity of energy used does not produce harmful effects on the patients. However, these mechanical vibration devices also have key limitations, because the bones and the air absorb almost all of the sonic beam, rendering studies of lungs, brain, or bones impossible with this technique. Finally, given the lack of a fixed projection of the organ under study, image production depends highly upon the operator and the direction of the sonic beam used (Mitchell, 1988).

The first commercial devices started as military equipment and were introduced in civil medical practice in the late 1950s and early 1960s. By the early 1970s, ultrasound devices were accepted as a diagnostic tool used by radiologists, cardiologists, neurologists, and neurosurgery specialists (Mitchell, 1988). By 1973, Picker, Unirad, and Smith Kline were the market leaders of these devices. Over the next few decades, continuous innovation would produce a myriad of technical improvements, from the incorporation of computers for information storage and control of wave sequencing to real-time imaging. Figure 7-a and 7-b show two older ultrasound models. Stressing the differences between the images produced with this technology and those produced by previous devices, Figure 8-a illustrates a typical ultrasound image of a fetus. Figure 7-c and

and Figure 8-b illustrate newer devices and images produced by these more advance ultrasound systems.

Similar to the emergence of the nuclear devices, new ultrasound devices came from academic laboratories, with industrial newcomers and diversifying firms actively participating in the technical improvement and commercialization of the devices (Mitchell, 1988). Incumbent manufacturers often started commercializing these devices after they acquired some of the initial technology innovators.

Ultrasound machines also brought new challenges to the diagnostic imaging community. Blume notes that, as the technology evolved, many questions emerged regarding on what basis and by whom this technique would be assessed (Blume, 1992). This is especially relevant, given that the early applications of this new system were focused on obstetrical and gynecological studies. This new area of influence would bring a new set of professionals to the community, and, consequently, a new set of relationships and interests:

> "In relation to obstetrical and gynecological applications, a particularly buoyant market was emerging […] This is to some extent to be understood in terms of a gradual displacement of x-rays, by this time acknowledge to be unsafe, from obstetrical practice. Obstetrical radiology was of course the province of the radiologist. Diagnostic ultrasound […] might provide a means of reducing the professional dependence of obstetricians on radiologists. We see that there are significant interests at stake here: not only radiological hegemony in the imaging field, but also the (possible) interest of obstetricians in rendering their own practice more independent. "(Blume, 1992: 109)

This professional "turf" battle over ultrasound devices would continue for many years, and it would likely contribute to the economical triumph of these devices. Their acquisition grew over time, with their average number of ultrasound devices within hospitals rising from 1.6 to 6.1 by 1980, and their reach spanning radiology, cardiology, ophthalmology, and obstetrics departments (Blume, 1992). The following subsection reviews the next significant technological innovation in this community: the CT scan.

X-rays Come Back! The Computed (Axial) Tomography Devices (CT, CAT)

While diagnostic imaging devices based on nuclear medicine and ultrasound were being developed and tested clinically, a different type of device would shake the community. The new technology took advantage of the cumulated improvements on X-ray detection and other subsystems, as well as the new capabilities rendered by the addition of computers to diagnostic imaging devices. Computed (axial) tomography (CT) machines were able to record more than 2,000 densities (whereas regular radiography was able to differentiate about 20) (Mitchell, 1988). This differentiation of densities allowed CT scans to distinguish fat from other soft tissues, but, more importantly, the machine could detect tumors surrounded by normal tissue. CT altered the diagnostic of multiple disorders (especially those within the cranium). In fact, CT completely changed the use of diagnostic imaging devices because they were faster, produced images with greater resolution, and reduced radiation exposure for patients and staff (Mitchell, 1988). Two types of these devices emerged during the creation of this technology: (a) brain-scanners or head-scanners, used to diagnose tumors, vascular diseases in the brain, and so forth; and (b) whole-body CT scanners, used regularly in abdominal and cardiac imaging. However, to obtain high-contrast pictures, it was often necessary to inject an invasive contrast material, and the devices were quite sensitive to patient movement (Mitchell, 1988). Figures 9-a and 9-b show an older and a newer model of CT scan devices. Images produced by these devices are shown in Figure 10, with Figure 10-a representing an older abdominal “slice” image and Figure 10-b representing a newer, high-definition (HD) slice of the lungs of a patient.

These devices were developed, at least initially, in the United Kingdom by the firm EMI, Ltd. During the early 1970s, EMI reaped the benefits of research funding by the British Department of Health. This research led to the construction of a head-scanner prototype that was tested at

Wimbledon Hospital during 1971 (Mitchell, 1988). By June of 1973, the Mayo Clinic and the Massachusetts General Hospital received the first CT systems from EMI (Mitchell, 1988), and by late 1973 six of these devices had been placed in the United States. The demand for these devices, despite the $400,000 price tag, exploded after they were presented at the Radiological Society of North America (RSNA) by EMI in November of 1973. EMI quickly capitalized on the development of this technology with sales of $20 million in 1974 and $60 million in 1975 (Mitchell, 1988). By 1975, seven other companies were selling CT devices, with five additional firms entering the industry by 1976, representing new firms (Neuroscan), diversifying companies (Pfizer), and manufacturing incumbents (GE and Siemens) (Mitchell, 1988). With this heightened competition, technical improvements occurred so quickly that CT scanners went through four generations of improvements in only four years, with the second and third generations appearing in 1975, and the fourth generation of significant technical improvements emerging in 1977, with EMI still holding a 40 percent market share (Mitchell, 1988). In 1978, however, the market for CT scans collapsed as buyers reduced their orders significantly (partially constrained by government efforts to contain costs in health care and partially due to the high uncertainty regarding which generation of CT systems would become the dominant design) (Mitchell, 1988). During the next two years, key market leaders of this technology would exit the industry because of the financial limitations and the heavy burden of new technological innovations. Only larger firms with strong financial situations and a corporate parent were able to cope with these financial restrictions, and a hefty consolidation changed the landscape of competition within this technological community. For instance, General Electric became one of the leaders in the manufacturing and commercialization of CT devices due to its acquisition of other key actors, such as Varian, Neuroscan, EMI, and Searle, and to its capabilities in radiological sales and services (Mitchell, 1988).

As it has happened with previous technologies, the development and adoption of this technology was influenced by the actors and the location of these devices within the health-care system (Blume, 1992). Although early studies suggested that the EMI scanners, as CT devices were early known, would be part of the province of neuroradiologists, others wondered whether neuroradiologists or their “neurological and neurosurgical colleagues, because of their specialized viewpoint” (Blume, 1992: 180) would be the best people to advise on the deployment of these instruments. Additionally, local states, trying to bring down health-care costs, and the federal government, through the Food and Drug Administration, would soon become a critical actor within this community—partially as a reaction to the perceived excesses in the acquisitions of these expensive, though not completely clinically proven devices (Blume, 1992).

In closing this section, it is important to stress that the sequential development of these devices is mainly an artifact created by the author of this investigation with the objective of presenting a clear evolution of the technological community at hand. In reality, the history of this community is much more complex, with multiple entanglements and overlaps among each of the technologies described previously, and with the evolution of one technology likely affecting the evolution of the next (see Table 1 for a quick overview of the overlap in the evolution of these technologies). This is especially important if one considers that none of these newer devices completely replaced the older ones, being, for the most part, complementary techniques, in which the strengths of one are the weaknesses of the next one, as shown in Table 2.

Now that the technologies and the community at hand are generally understood, it is time to clarify the role of the central actor in this investigation: the American College of Radiology. The following subsection provides a historical account of this organization to explore the role it played during the aforementioned technology evolution.

The American College of Radiology (ACR): 1923–Late 1970s[7]

As noted before, the diagnostic medical imaging community started with the development of X-ray machines. Likewise, the history of the American College of Radiology is linked strongly to these devices and to the certified physicians who are in charge of interpreting their output—the radiologists. Although, nowadays professional jurisdiction (Abbott, 1988) over this type of device is out of the question, during the first years after the creation of X-rays devices, who had the skills to create and interpret these images was unclear. As noted by Dewing (1962):

> They were many non-medical persons ranging from physicists, engineers, and electricians through nurses, hospital orderlies, and photographers, to frank charlatans and sideshow exhibitor types. These later did little to elevate the professional level of radiology and insofar as they were in the public eye, damaged its tone. It took some years before the more professional physicists and engineers either entered medicine fully… or lost interest and return to their primary academic or commercial pursuits. It took a little vigorous shaking to root out the riff raff. But by 1905, the ***conscientious physicians*** were in the ascendance, and ***have kept control fairly well since*** (Barley, 1984: 21 emphasis added)

These "conscientious physicians" started to win the battle for the control of these devices when they began to organize themselves as a coherent group with defined goals. Although physicians already counted with at least three leading organizations (Linton, 1997)—the American Roentgen Ray Society (ARRS, founded in 1900), the Radiological Society of North America (RSNA), and the American Radium Society (ARS) (both founded in 1916)—it was the funding of the American Board of Radiology (ABR) in 1934 that significantly changed the stature of the profession. The establishment of the ABR allowed physicians to gain legitimacy through the approval of an examination administered by the American Medical Association (AMA). In gaining this certification, radiologists established themselves as a formal medical specialty (Barley, 1984).

However, even before obtaining this critical endorsement by the AMA, many of these physicians were concerned with the common problems and attracted by the shared interests of radiologists. In late 1922, Dr. Soiland, a former president of the RSNA and a prominent radiologist working in Los Angeles, sent a letter to a group of friends asking them about their interest in forming a new national radiology group. Although many of the recipients of this letter were men who had held prominent leadership roles in scientific societies, they agreed with Dr. Soiland's assessment regarding the mishandling of multiple issues by the three leading national radiological groups. On June 26, 1923, during the annual meeting of the American Medical Association (AMA) at the Palace Hotel in San Francisco, 21 of the 70 professionals answering the original letter from Dr. Soiland were the charter fellows of California's newest not-for-profit organization: the American College of Radiology.

The raison d'être for these professionals was their distress in seeing that their role as radiologists, as referral specialists, detracted from their image as physicians. They were perturbed that hospitals were hiring radiologists as employees, rather than treating them as professionals, alongside other physicians on their staff. Given their self-trained status, they were also concerned with improving training for those already in the practice, but, more importantly, for those young physicians who would follow. Lastly, "they were concerned about assuring the future of a specialty to which they had pledged their careers" (Linton, 1997: 2). Dr. Benjamin H. Orndoff of Chicago, another former president of the RSNA, prepared the constitution and bylaws of the new organization. The purpose of the ACR was "to create a *fellowship among medical men*, who have distinguished themselves in the *science of radiology*" (Linton, 1997: 3 emphasis added). The number of fellows was limited to 100, with new fellows entering only to replace those who died. A 10-man board of chancellors would have full power to run the organization without consulting the other fellows. The chancellors and the executive secretary were offices with terms set at five years. Dr. Soiland chose to start as executive secretary, with Dr. Orndoff as treasurer. As its first president, the group chose Dr. Pfahler, a former ARRS president and a leading teacher of new radiologists.

In June 1924, the ACR held its first convocation in Chicago, along with the AMA annual meeting. Taking advantage of their participation in the AMA annual meeting, ACR officials created a Committee on Hospital Standards and were able to meet with the AMA president to discuss their concerns about the status of radiology as a profession in hospitals across the country. Although, the first years of existence of the college were challenging and, on occasion, its continuity was in doubt, the organization was able to survive, holding convocations and initiating new and honorary fellows at International Congresses of Radiology in 1928, 1931, and 1933. In fact, in 1928, the bylaws were modified to eliminate the cap of 100 fellows as a way of infusing new funds to the organization. By 1933, the internal structure of the college started to diversify, creating nine standing committees of three members each, while the organization began to be involved in issues affecting radiology. Out of these committees, three in particular would have a strong influence in the developments of radiology: one exploring the development of a national board for radiology, one looking at the cost of medical care, and one studying radiological training and public education about radiology (Linton, 1997).

Over this period, the ACR started channeling complaints and concerns from radiologists across the country regarding difficulties and undesirable practices that they were encountering at their local hospitals. Perhaps more importantly, the ACR actively participated in two key activities. First, in conjunction with the AMA's Section Council on Radiology, the ACR sponsored the creation of the American Board of Radiology, establishing radiology as a formal medical specialty. It is evident that the ACR was consequential to the creation of the profession by promoting the creation of the ABR, and, thus, the defense of the profession would continue to be a central issue in ACR's purpose over time. Second, the ACR established a registry of trained technologists (technicians who possess certain specific training to operate the machines and to produce the radiographs needed by the radiologists), directing the certification of their training program, shaping the content of their curriculum, and even setting terms for their employment as supporting personnel (Barley, 1984). This control of the supporting technicians' training was important because radiologists were able to make sure that certified programs would exclude instruction in reading radiographs, the key jurisdictional claim for radiologists.

The coming decades brought growth and improvement to radiology as a profession through more sophisticated and safer equipment. The evolution in equipment also brought a larger number of physicians interested in the better and safer devices. These changes, however, did not alter the purpose of the organization as the voice of a radiology community for physicians who should be treated as professionals, not mere employees of hospitals, as ACR President Thomas Grover noted in the 1935 Annual Meeting Presidential Address:

> "As I think of the ACR, I envision it as having survived the infantile and adolescent periods and now about to emerge into its adult stage of the development. *Radiology must be clinical practice by broadly trained physicians* and not just a technical service by "plate readers."(Linton, 1997: 12 emphasis added)

By the mid-1930s, ACR's membership included 220 fellows in total, with nine standing committees: Fellowship; Finance; Life Fellowship and Endowment; National Board of Radiology; Cost of Medical Care; Revision of Constitution and Bylaws; Colleges, Hospitals, and Radiological Education; Public Instruction; and Radiological Jurisprudence. This specialization and growth in the activities of the organization crystallized in 1937, when a permanent office was opened in Chicago, where the chairman and an executive secretary would handle all the administrative tasks for the operation of the college. This also brought other changes, such as a new constitution and a new leader. The new leader, Dr. Chamberlain, an original member of ACR and its Board of Chancellors, significantly shaped the actions of the ACR for the next five years. He transformed the organization into "the undisputed economic spokesman for radiology," with the strength and resolution to stand up to hospitals, the new health insurance companies, and the social reformers in Washington, as well as "*anyone else who challenge the future of radiology*" (Linton, 1997: 13 emphasis added). These statements reaffirm ACR's mission, but also allow us to see who the leaders of the organization perceived as critical actors in "legitimating" the radiological profession.

However, ACR's leaders quickly realized that if they were to succeed, they would need to become involved in the efforts of other key representatives of the profession. For this reason they created the InterSociety Committee (ISC). This committee was a way of crystallizing the interests of radiologists from the combined sponsorship of the ARRS, ARS, and RSNA (who contributed $15,000 annually for its activities), but maintaining them within the structure of the college. Embodying the interests of all American radiologists through the creation of this structure within the college resulted in multiple successes in defending the profession and in extracting positive outcomes in negotiations with other institutional actors and the government. ACR officials argued that the success achieved by the ISC was evidence that the ISC was an entity that combined the interests of all radiology. This "machinery [should be] retained to permit the other national societies to share in the direction of all projects pertaining to the social problems and the economic welfare of radiology" (Linton, 1997: 28). In turn, bringing the interests of other actors internally to the college very likely affected the mission, leadership, and actions of the ACR. One of the key early actions of this commission was to gain the support of

AMA in resisting hospital control on radiology. This support crystallized in a resolution by AMA recommending that any "hospital found to be treating physicians unethically should be removed from the AMA's list of approved hospitals for intern and resident training" (Linton, 1997: 17). However, ISC's efforts did not finish there. Soon after this resolution, an influential group of radiologists representing ISC met with a delegation of the American Hospital Association and was able to draft a concrete protocol defining the organization of X-ray departments. This document was critically important for radiology, because it was the first time that the American Hospital Association recognized them as a "member of the medical staff […] director of a separate clinical department [and] the assertion that the technical components of the service [radiologists provided] should not be separated from the professional elements for billing purposes" (Linton, 1997: 22).

Because of these significant accomplishments, ISC became so important within the ACR that the organization amended its constitution and bylaws to include appointees from each of the three scientific societies to the ACR's Board of Chancellors, which thereafter took over certain functions and responsibilities assumed by the ISC. In part, the addition of chancellors from the ARRS, the RSNA, and the ARS provided these societies with direct input to ACR policy and programs, but also, the "leadership of all the radiological societies remained within a small group of men, most of whom had held office in more than one society" (Linton, 1997: 33-34). Besides being concerned with the hospital status of radiologists, the college gained the support of the General Electric Company (GE) for the production of a movie about radiology: *Exploring with X-rays*, which was completed in early 1941.

In the 1940s, the ACR kept its promise of representing the interests of radiologists while equipment and techniques were refined. In 1942, for instance, the college became a sponsor of the American Registry of X-ray Technologists (Linton, 1997). In 1945, the ACR lead the celebration of the 50th anniversary of the discovery of X-rays, assisted by a $15,000 contribution from the X-ray section of the National Electrical Manufacturers Association (NEMA). During this period, film, contrast, high-energy sources for radiation therapy, and residency programs all improved, solidifying the standing of the radiologist as a specialty physician. Participation in college activities reached well beyond the members of the Board of Chancellors, who still held exclusive control of the leadership of the organization. As the 1940s came to an end, ACR achieved "recognition as the national spokesman for radiology on practice issues. It was recognized by federal agencies, medical groups, and hospital organizations as representing the majority of radiologists"(Linton, 1997: 41).

In 1950s the ranks of radiology "were swelled by physicians who became acting radiologists in military service and elected to get formal training and certification for a civilian career in the specialty [and] a wave of hospital constructions, […] provided practice opportunities for younger radiologists without threatening the exclusive contracts of senior specialists" (Linton, 1997: 43). Along with this increase in the ranks of radiology, the ranks of ACR also grew, although the internal structure and the mission of the organization remained almost unchanged. As Linton (1997: 44) noted, the mission of ACR continued to be "to define and protect the specialty of radiology against all of its challengers." One way in which the ACR enacted this purpose was by representing radiology in its struggle against health insurers and hospitals that continue to regard radiology as a hospital "service."

However, the ACR's relationships with these actors were multifaceted. The ACR collaborated with hospitals to develop standards for equipment and for the management of radiological departments and worked together with health insurers (such as the National Association of Blue

Shield Plans) in creating protocol and nomenclature standardizing usage and making it possible to determine what procedures could be used as the basis of a charge (Linton, 1997). Additionally, the role of councilors from the state societies gradually took on more substance, which began to change the internal relationships that had governed the college in the earlier decades. More importantly for this investigation, perhaps, was the growing use of radioactive isotopes by a multitude of radiologists and the ACR. It is for this reason that in 1955 the Board of Chancellors proclaimed, "The use of radioactive isotopes […] is *part of radiology.* The Board believes that standards of training and of proficiency at comprehensive levels are properly the province of the American Board of Radiology" (Linton, 1997: 50 emphasis added). However, their actions did not end with this proclamation. Soon after, the college funded a public relations effort with the support of Eastman Kodak, publishing an article in *Readers Digest,* later buying and handing out 100,000 copies among its members to be distributed to the public. The college also decided to begin a quarterly publication called *Your Radiologist* and to publish and distribute a pamphlet, *X-rays Protects You*, for general audiences. Finally, in 1958, the ACR completed a movie (funded in part with the collaboration of the DuPont Company), *First a Physician*, depicting the role of radiologists in patient care.

Notwithstanding these public relation efforts and parallel efforts within the AMA, the ACR could not avoid acknowledging that a large number of physicians were using isotopes to diagnose and treat patients and were achieving a separate status as a medical specialty, severing their ties to radiology or pathology. With the emergence and popularity of the gamma camera, many new practitioners were attracted to the field of imaging. The ACR's position was that "the medical use of radiation from any source was a natural and proper part of the specialty of radiology" (Linton, 1997: 82). This view was highly contested by pathologists, internists, and others using diagnostic isotopes for imaging and analytical procedures (Linton, 1997).

By the early 1960s, technical breakthroughs and legislative initiatives would reshape the practice of radiology, and consequently the ACR. By 1963, the Board of Chancellors had formally approved the state chapter that sent delegates to an assembly that gained the right to elect a chancellor each year by 1964. This year was also quite significant in terms of the ACR's influence on the diagnostic medical imaging community. First, the Food and Drug Administration (FDA) ask the college for advice on whether to allow certain radioactive products to be use in medical imaging. This began the ACR's key mediating role, "positioning itself as a body of experts on radiation use, experts who had much to contribute to public policy on that subject"(Linton, 1997: 63). In the same way, when the Bureau of Radiological Health devoted its efforts to setting standards for television sets and medical units, "the ACR had full access to its deliberations, and the resulting regulations" (Linton, 1997: 63). Additionally, the Public Health Service awarded the college a $10,000 grant to develop a computer glossary of radiologic terms, along with similar glossaries from other disciplines. However, the most important actions that the college would engage in would be its efforts to "rescued [radiology] from legislatively mandated segregation from the rest of medicine" (Linton, 1997: 67). This critical resolution was won by a single vote in a congressional committee, in which radiology was decreed to be a medical specialty and not a hospital service.

By 1968, the council began to consider itself as *the* representative body of the college, asking the Board of Chancellors to surrender its policy-setting role, a significant governance change that was approved in 1969. Another profound change occurred the same year. Considering the large amount of ACR activities now linked to governmental agencies, the board and council approved the opening of a permanent office in Washington DC. Within six months, this new office garnered enough projects from the federal government that it was able to cover its operating costs (Linton, 1997). Along with these internal changes, the ACR reaffirmed its commitment as "the radiological association" when it funded the production of a book crystallizing the history of radiology in the United States, a work assigned to leading science writers Ruth and Edward Brecher. Concomitantly, a library and a museum focused on preserving the history of radiology became a primary ACR responsibility—a consequence of the efforts of an influential group of members, the Gas Tube Gang, who created the American Institute of Radiology inside the ACR. During this period the ACR had "learned to relate to the federal government successfully, first by lobbying Congress, and then by setting up its own staff to relate to the federal bureaucracy. Its membership and budget were bigger than ever. Radiology was thriving" (Linton, 1997: 64).

By the early 1970s, the ACR had become even more complex, creating specific functions and personnel for dealing with the federal bureaucracy, obtaining government funding for an increasing array of educational and research activities. During this period, the ACR significantly shaped the growth and acceptance of mammography by publishing a series of guidelines on the use of this new technology, such as biennial and annual screening programs, and cosponsoring a series of scientific conferences, even though most physicians were reluctant initially to "refer patients for screening or clinical mammography" (Linton, 1997: 100). In fact, Linton (1997) even argued that this involvement in facilitating the acceptance of mammography could have reshaped the ACR, because the self-referenced mammography exams likely implied the need for direct contact and responsibility to advise the patient in accordance to the radiologist's interpretation of the exam.

However, mammography would not be the only technology-focused issue that would attract the attention of the ACR. For example, the quarrel with nuclear medicine over the professional jurisdiction of gamma cameras and other nuclear medicine imaging devices dragged on for an entire decade until it reached the Council on Medical Education (an internal structure within the AMA designed to deal with professional jurisdictions). Even with ACR objections, the council approved the creation of a conjoint American Board of Nuclear Medicine in 1971. The conjoint nature was a concession to the ABR, the American Board of Pathology, and the American Board of Internal Medicine (Linton, 1997). The ACR engaged in an equivalent squabble with cardiologists and obstetricians over the control of ultrasound devices and the interpretation of the images they produced. By 1973, the ACR was successful in persuading the Medicare program to begin paying for diagnostic ultrasound examinations (Linton, 1997). With the cooperation of the American Institute of Ultrasound in Medicine, the American College of Cardiology, and other groups representing physicians who used ultrasound, the college convinced the federal administration that most uses of ultrasound were no longer experimental. This victory translated into the coverage of ultrasound studies under the radiology section of the AMA's Coded Procedural Terminology classification (Linton, 1997). Shortly after, a group of cardiologist protested the Medicare requirement that they bill echocardiography procedures as radiology. This action pushed Medicare to reconsider their protocols. Lastly, the display at an RSNA convention of a computerized axial tomography (CAT), which made cross-sectional images of the head with the aid of complex computer programs, also pushed the ACR to assert their professional jurisdiction (Linton, 1997).

However, a few years into the decade, the ACR was able to confront successfully all these jurisdictional problems. As Linton notes, "The ACR was relatively successful in stalking out ultrasound and computed tomography as radiology. For much of the decade, the Joint Commission on Accreditation of Hospitals imposed a policy on its participating institutions that called for the interpretation of all imaging procedures by the designated radiologist" (Linton, 1997: 81). These effective organizational relations with key institutional actors became the trigger of sustained internal growth. This growth crystallized in the opening of a permanent office in the San Francisco area, and a group of researchers stationed in Philadelphia. By 1977 all these new activities took their toll on the financial position of the college, when the new treasurer informed the members that for the first time in the history of the organization, the ACR had a deficit of $340,000 (Linton, 1997). This was not a minor problem, and the treasurer noted that if these trends were not reversed, the organization could bankrupt in two years (Linton, 1997). By the end of that year, the financial situation was reversed and the budget was balanced, but this delicate situation would influence the actions of the ACR in the years to come.

As the influence of the ACR increased, typical radiological practices matured too, increasing the number of devices in use as well as the number and type of personnel involved in their operations. Now, not only could one find a group of radiologists and technologists in a typical hospital-based radiological department, but also business managers or radiological administrators who influence the personnel, administration, and finances within these units. In fact, some evidence indicates that the incorporation of these new professionals facilitated the beginning of a phenomenon that would intensify in the coming years: the establishment of imaging facilities outside the hospitals (Linton, 1997).

All the actions the ACR took during this and previous decades *conceivably prepared this organization* for the taxing technological changes that the 1980s would bring. However, before going into the details of what happened during that period, it seems important to explain the methodological choices made when collecting empirical evidence for this investigation. The next chapter takes on that task.

CHAPTER IV: METHODS AND DATA

Methodological Considerations

This is unequivocally an inductive change study; one particularly centered on a specific organization (the American College of Radiology). The direct goal of this study is to explore how the American College of Radiology was able to respond effectively to a seemingly insurmountable disruptive technological change (the emergence of NMR devices). Additionally, this investigation seeks to explore the underlying reasons behind this improbable effective response—why this organization was able to effectively respond to this technological disruption when most previous research suggests that this type of response is highly unlikely, if not impossible.

In general, investigations within organizational studies do not presuppose a particular methodological approach, or even a preferred ontological posture (Azevedo, 2002; Chia, 2003; Donaldson, 2003; Hatch & Yanow, 2003; Tsoukas & Knudsen, 2003; Willmott, 2003). In fact, there seems to be certain openness to consider alternative methodological approaches (Bryman, 1989; Czarniawska, 1997; Elsbach, 2005; Gephart, 2004; Larsson & Lowendahl, 1996; Lee, 1999; Linstead, 1997; Morrill & Fine, 1997; Van Maanen, 1998; Wagner, Bartunek, & Elsbach, 2002; Yanow, 2000). Organizational change studies, in particular, have used various methodological approaches in the past (Lewin, Weigelt, & Emery, 2004; Poole, 2004; Poole & Van de Ven, 2004; Poole *et al.*, 2000; Tsoukas & Chia, 2002; Van de Ven & Poole, 1995, 2005). However, this diverse spectrum of methodological approaches does not mean that any methodology is appropriate for any specific study. Indeed, there seems to be an agreement among the scholars within this field that, although no single approach is necessarily superior to any other under any circumstance, methodological approaches need to be chosen in accordance with the specific research question and context to be studied (Poole *et al.*, 2000). Considering that this investigation is an inductive change study and a project focused on a "how" research question, it seems logical to use a process-centered approach (Mohr, 1982; Nayak, 2008; Poole *et al.*, 2000; Scott, 1994; Tsoukas & Chia, 2002; Van de Ven & Poole, 2005).

Nonetheless, process-centered research is understood differently in different quarters. Thus, it seems important to clarify how this approach is used in this investigation. Two alternative understandings of process-centered research have been offered: a "weak" view "treats processes as important but ultimately reducible to the action of things, while a 'strong' view deems action and things to be instantiations of process-complexes" (Chia & Langley, 2004: 1467). The former tends to be "pragmatic, empirically grounded, and analytical in orientation," whereas the latter "has been primarily conceptually, strongly informed by strands of process philosophy, theology and the humanities at large, following especially the lead of philosophers such as James, Whitehead, Bergson and Deleuze" (Chia & Langley, 2004: 1467). These scholars stressed that "for those adopting a strong view, processes are thought real whilst substances, entities and things are secondary conceptual abstractions [where] change and becoming need to be constructed not as secondary, but as the *sine qua non* of organizational life. While the first perspective helps us to observe processes, the latter enable us to appreciate the *sui generis* nature of process" (Chia & Langley, 2004: 1467). Considering that the ontological posture taken in this investigation is one in which organizations are conceptualized as social actors, or real entities (Van de Ven & Poole, 2005), it is logical to espouse here what Chia and Langley coined as a "weak" perspective on process research.

This "weak" perspective has been used within organization studies in the past. For instance, Cohen, March, & Olsen (1972) developed a model to strategic decision making using this methodology, and Gluck, Kaufman, & Walleck (1980) studied strategic planning in an organization following this process-centered approach. In fact, process research seems to be gaining new relevance within organizational studies through conceptual (Pentland, (1999); Langley, (1999)), and empirical examples (Das & Van de Ven, (2000); Yu, Engleman, & Van de Ven, (2005)).

This approach to the study of change seeks to construct a timeline to identify all the special circumstances that caused specific and possibly unexpected twists and turns. Process research, as noted before, seek to track how forces initiated in one event are transmitted or dissipated in subsequent events, and how a conjunction of events build momentum or change the process"(Poole *et al.*, 2000). Bearing in mind that explanations of change ought to integrate all types of forces that influence the process, this approach considers "continuous and discontinuous causation, critical incidents, contextual effects and effects of formative patterns"(Poole *et al.*, 2000: 4). This methodology also has the ability to unveil the generative mechanisms, the "fundamental motors" explaining a specific change process (Van de Ven & Poole, 1995). In contrast with variance models in which choosing the appropriate variable is a key aspect, within process research, explanations center on "discerning essential central subjects and the types of events and characteristics that mark qualitative changes in these subjects"(Poole *et al.*, 2000: 39). Events often consist of individual or collective action, but they might also bring about changes in context that influence the developing entity. Through events "the various forces that influence development and change, continuous and discontinuous, local and general, come into play" (Poole *et al.*, 2000: 5).

In particular, when espousing a "weak" perspective on process research (Chia & Langley, 2004), defining and identifying events constitutes one of the main challenges a researcher confronts.

Proponents of this approach have stressed the importance of clarifying the difference between events and incidents. Incidents are the raw data, descriptions of a happening, or documentations of something that occurred. In contrast, events are “meaningful parsings of stream incidents […constructed from a] systematic interpretation by the researcher of what is relevant for the process” (Poole *et al.*, 2000: 131). In other words, incidents reflect the raw data through which the investigator develops the second-order data denominated events. The relationship between incidents and events is one that develops over time throughout the analysis of the data, involving an “iterative process of developing initial conceptual categories, observations and progressive redefinition and refinement of categories” (Poole *et al.*, 2000: 130).

This iterative process of progressive redefinition is linked closely to the entity under study, because events are what central subjects do or what happens to them and are the building block that allows the researcher to produce a coherent story or narrative of the process unfolding. In other words, *“central subjects* are individual entities […] around which the narrative is woven” (Poole *et al.*, 2000: 40). Process research, then, “must convert a heap of confusing data into a synthetic account in which readers can comprehend all the data in a single act of understanding. This requires the ability of recognize recurrent patterns in event sequences, to establish necessary connections, and to identify formal and final causation […more importantly one must present] a synthetic move that comprehends all the particular evidence as part of a larger pattern”(Poole et al., 2000: 54/55).

Now that I have justified, in general terms, the methodological approach chosen for this investigation and elaborated on the reasons why it seems logical to use it considering the research questions presented above as well as my own ontological presumptions of the entity under study, I can describe the data sources used to collect the data.

Data Sources

The central tenet of the methodological approach described above is being able to reconstruct the series of events that precipitated the changes within the entity under study. Considering that the emergence of NMR devices (the key disruptive technological change around which the study is mostly focused) unfolded during a relatively long period (early 1950s–late 1980s), I relied heavily on archival sources and historical evidence (Elder, Pavalko, & Clipp, 1993; Henige, 2005; Hill, 1993; Jones Shafer, 1980).

The identification of incidents (raw data) through the "analysis of documents and records, retrospective interviews, bibliometric analysis and other historical-reconstructive methods" is appropriated for this methodology according to Poole and colleagues (Poole *et al.*, 2000: 136). In fact, specifically for studying processes, archival research has been argued to have some advantages. First, researchers have the benefit of hindsight (Poole *et al.*, 2000). Second, if adequate records are available, the data can be examined and reexamined, coded in multiple layers until the full story emerges without the risk of missing any concurrent events (Poole *et al.*, 2000). Third, lengthy processes can be studied in comparatively brief periods. In other words, researchers with access to good records can explore a process lasting multiple decades (Poole *et al.*, 2000).

I relied on two main sources to collect information about the central actor in this investigation: the ACR. First, I reviewed and collected data from a detailed historical reconstruction of the history of this organization recently published by one of the ACR key leaders: Otha W. Linton (1997). According to the proceedings of the 80th annual ACR meeting (2003), Otha Linton was known as "Mr. Radiology" or "Mr. ACR." Between 1961 and 1997, while serving in the ACR as its director of public relations, then, as its director of government relations and, finally, as associate executive director, Linton had a critical role in advancing both the ACR and the practice of radiology. His service to radiology was rewarded with multiple awards—from being named as honorary member of the Radiological Society of North America to being recognized for his "distinguished service by a layman citation" by the American Medical Association. Mr. Linton's recount of the history of the ACR was a key source for enhancing my understanding of the organization from the perspective of a key insider.

This historical narrative was especially useful because it covers the history of the central organization under study from its inception in the early 1920s to the mid-1990s, thus covering a critical time in the ACR's history when the organization had to respond to the emergence of NMR devices. Having this historical account is especially useful for process-centered research because of this approach's commitment to the serious consideration of an entity's past as one of the potential critical drivers of current behavior. Notwithstanding these strengths, Linton's narrative was created to provide current radiologists with an internal recount of many critical developments within radiology, and thus to help them understand the history of their profession and the role that the ACR played in current practices, policies, and technologies. However, for this investigation, the depth of information about one particular period is quite limited. In other words, Linton's historical overview is an irreplaceable background source for multiple aspects of the ACR's priorities, mission, governance, actions, leaders, and so forth, but it cannot be the only source for a detailed study of a particular event or events in the long history of this organization. Thus, complementing Linton's history of the organization, I gathered most of the data used in the central analysis of this investigation from an alternative source: the actual historical archive of the ACR.

As I have briefly noted before, the ACR has as one of its mandates, deeply rooted in its history and mission, the task of preserving the history of radiology. That is why, since the early 1970s, the ACR has devoted a large amount of resources to collect and preserve a wide variety of documents and memorabilia and has even conserved the personal archives of key figures in the history of the profession. Paralleling this effort to ensure the history of the profession, the ACR maintains a large archive of its own history, holding past documents, memos, minutes, and annual and technical reports, among many other materials. This preservation of the past is taken so seriously that they have hired a specialized firm, the History Company, not only to help them with the administration of this historical archive, but also with the responsibility of continuing the preservation of the current and future documentary evidence of the activities of the profession and the organization. Taking advantage of this rich archive, I was granted permission to visit and review a wide variety of documents pertaining to the history of the ACR. After reviewing the contents of these documents, I had to pay a nominal fee[8] to gather specific information, in the form of pictures and photocopies of selected documents, monthly publications, technical reports, and leadership communications.

In addition to the data collected within the ACR, I also decided *to consider specific information about two interrelated parts* of the overall technological evolution process**.** First, I reviewed the history of the community as a whole, in order to gain supplementary insights about the technologies embedded in this community and the role that the ACR has played in its different historical periods (a substantial part of this data was summarized in the previous chapter). Second, and perhaps more importantly, I reviewed in detail the complete process of the emergence of the disruptive technology (NMR devices) that served as a key stimulus or disruptor of the community and particularly of the ACR. Although I have not treated the information focused on NMR's evolution in the same way that the information collected on the ACR's actions, I have been able to reconstruct the critical occurrences within its own evolutionary process. The creation, development, and commercialization of NMR devices was followed thoroughly, given the potential interdependences and influences that creators and their actions might have had in the evolution of this technology and in the actions of the ACR. In so doing, I used multiple sources from several books describing different scientific aspects of NMR and its creation, as well as the personal experiences of some of the creators of the technology; the detailed reconstruction of the evolution of NMR devices is presented in the next chapter. Moreover, I gathered data from the most important journal of this industry, Diagnostic Imaging, a publication highly used by industry insiders and by previous investigators in this industry, published monthly between 1979 and the present. This journal presents a format that allowed me to review different aspects of the industry—from regulation to technological innovation, from business news about each organization in the industry to new medical applications of the emerging technologies, as well as editorial and professional opinions on how these technologies were affecting the industry as a whole. In addition, I also collected some data from the journal Radiology, published by the Radiological Society of North America (RSNA). The information used to triangulate different aspects of the history of the (1) diagnostic medical imaging community, (2) the emergence of NMR devices, and (3) the ACR's actions, including authors, year of publication, and other information on the main sources are synthesized in Table 3.

From Methods to Data: Data Gathering and Initial Exploration

Figure 11 summarizes the methodological procedure used in gathering and later analyzing the data for this investigation. Phase I of this procedure focused on discovering the most relevant data, and later on gathering the selected information in the form of an incident sequence. Phase II corresponded to the identification of events and their initial exploration. Phases I and II will be described below.

Phase I: Data Discovery and Gathering

As noted before, the raw data under this methodological approach are incidents. Poole and colleagues (2000: 133) defined an incident as a qualitative datum that contains "(1) a bracketed string of words capturing the basic element of information (2) about a discrete occurrence (3) that happened on a specific date. Each of these incidents must then be entered as a unique record in a qualitative data file, and subsequently has to be coded and classified as an indicator of a theoretical event (Poole *et al.*, 2000). However, in this definition, there is no specific guidance regarding what is a relevant or consequential occurrence, or, in other words, what is an incident and what is not. Poole and colleagues noted that explicit decision rules ought to be devised and they "should reflect the substantive purposes of the research" (Poole *et al.*, 2000: 133). For this case, then, I chose to define them in accordance to my central subject, the ACR, and the process I am trying to explore. Although the ACR, as with any other professional association, can be easily conceptualized as a community actor, one should recognize that these professional societies are also formal organizations (Friedman, 2004); thus, I can conceptualize its actions by relying on extant organizational frameworks. Additionally, the ACR's responses to the emergence of NMR devices can be described as a change process, or in broader terms as an adaptation process. Thus, it might be useful to consider the broader organizational change and adaptation literature when seeking insights on what type of occurrences can be relevant to study the way in which the ACR adapted to the emergence of NMR devices. I do so in the following subsection.

Incident Definition: Theoretical Background & Initial Rule

In reviewing the adaptation literature, one could argue that the broad study of change and adaptation has had a prominent role in the research agenda of organizational scholars (Greenwood & Hinings, 2006; Hinings & Greenwood, 1988; Hinings, Greenwood, Reay, & Suddaby, 2004; Pettigrew, 1985; Poole *et al.*, 2000; Selznick, 1949; Van de Ven & Poole, 1995; Zald & Denton, 1963). Diverse theoretical and empirical approaches have been used for the study of this issue (see Barnett & Carroll, 1995; Poole, 2004; Tsoukas & Chia, 2002; Van de Ven & Poole, 2005; Weick & Quinn, 1999 for influential reviews). The arguments offered by those investigations have focused on the firm level of analysis, on the boundary between firms and the proximal environment, and even on the link between firms and the macro environment (Lewin *et al.*, 2004). The arguments that stemmed from those different approaches present a wide range of ideas regarding organizations' ability to adapt.

At one end of the spectrum, some scholars consider incumbents' adaptation as improbable or unlikely. Among those in this camp, one could single out arguments offered by scholars within population ecology (Hannan & Freeman, 1984; Ruef, 1997), and some strong neoinstitutional positions (D'Aunno, Succi, & Alexander, 2000). Similar arguments regarding the likelihood of adaptation are taken by scholars using tenets of industrial organization economics (Porter, 1981) and by those stressing the power of organizational identity as category (Hannan *et al.*, 2006; Hsu & Hannan, 2005; Jacobs, Christe-Zeyse, Keegan, & Pólos, 2008; Pólos, Hannan, & Carroll, 2002; Zuckerman, 1999, 2000; Zuckerman & Kim, 2003; Zuckerman, Kim, Ukanwa, & von Rittmann, 2003). On the other hand, researchers relying on other theoretical frameworks have portrayed incumbents as entities that can overcome inertial constrains. Within this camp, one can isolate research using resource dependence theory (Pfeffer & Salancik, 1978 [2003]) and some institutional arguments (Kraatz & Zajac, 1996; Oliver, 1991). Similarly, research using strategic choice (Child, 1972; Miles & Snow, 1994) and members' focused organizational identity arguments (Corley, 2004; Dutton & Dukerich, 1991; Elsbach & Kramer, 1996; Fiol, 2002; Fox-Wolfgramm, Boal, & Hunt, 1998; Gioia & Thomas, 1996; Whetten & Godfrey, 1998) have stressed the adaptation capabilities of organizations. Finally, and offering a more extreme stance, a group of researchers linked to the "old institutional theory" have argued that organizations are, by nature, adaptable entities (Clark, 1956, 1970; Selznick, 1948, 1949, 1957 [1984]; Zald & Denton, 1963).

Given that the main objective of this project is trying to understand how and why the ACR was able to respond effectively to the challenges posed by the emergence of NMR devices, the arguments most relevant for this research project seem to be those stressing the possibility of organizations to adapt to environmental changes. Although old institutional, resource dependence, strategic choice, and identity arguments underline different organizational variables and processes when explaining the ability of organizations to adapt to different environmental threats, they also share some key ideas. Arguably, three common ideas can be extracted from these theories that stress the ability of organizations to adapt. First, adaptation depends heavily on organizational leaders' interpretations and actions when environmental jolts occur. Second, the way in which these leaders are able to shape others' perceptions and emotions is critical in the outcome of the adaptation process. Finally, the external actions—the relationships the organization under study has with other actors—and resources that leaders choose to use during these complex adaptation processes are also critically consequential in the outcome of the adaptation effort.

In addition to gathering insights from studies on organizational adaptation and change, some ideas can be imported from studies focusing explicitly on professional associations. Indeed, professional associations have been the locus of multiple investigations within organizational studies. However, most of these research endeavors have centered on understanding how these organizations shaped different inter-organizational dynamics (DiMaggio, 1991; Galvin, 2002; Greenwood, Suddaby, & Hinings, 2002; Lounsbury, 2002; Washington, 2004).

In contrast, few investigations have focused on these professional societies as organizations in their own right or in the intra-organizational processes that allow them to adapt to changes in their environment. Specifically, a set of works within organizational studies and a couple of research projects from a historical viewpoint were found to tackle directly the issue of professional associations' transformations. The latter set of investigations studied the Southern Sociological Society (Simpson, 1988) and the American Sociological Association (Simpson & Simpson, 1994). Although these investigations were not aimed to study adaptation per se, the authors highlighted key insights related to the transformations that these professional societies went through. First, the evidence indicates that these associations were able to adapt to multiple environmental jolts by shifting their founding goals. This process was the consequence of changes in the composition of their membership and the redefinition of their bylaws. Finally, these investigations also underscored the importance of specific, diversified organizational structures created by those associations to co-opt particular constituents when explaining the ability of these organizations to adapt. The former set of works presented only a normative case suggesting what type of governance models are likely to produce professional associations that are more proactive when adapting to changes in the environment (Friedman, 2004; Friedman & Mason, 2006). Arguably, the insights gained from the limited empirical evidence dealing specifically with the adaptation of professional associations indicate that successful adaptation is commonly linked to mission displacements, some specific actions of the leaders of these associations, and the co-optation of critical constituents. Thus, I relied on all the insights from the general organizational adaptation literature and the specific study of professional associations to define what types of occurrences I would explore when seeking to understand how and why the ACR was able to respond effectively to NMR.

As a starting point for my inductive gathering efforts, I focused my attention on the changes and activities the ACR engaged in its *internal organizational structure, its mission and by laws, as well as the actions of ACR's leaders*, and any *changes in the leadership team*. In addition, I assessed whether the *organizational identity* of the ACR changed in the period under study. Finally, when considering the insights coming especially from old institutional theory and resource dependence, I followed the *changes in the relationships that the ACR had with a multitude of other actors* in the technological community.

Then, based on the common themes stressed by those who have studied organizations that underwent successful adaptation reviewed above, I decided to define as my initial incidents three types of activities or changes in the actions of the ACR. First, those linked to changes or activities internal to the organization—those contained within the boundaries of the organization and its members. The second type of potentially relevant occurrences includes the different relationships that the ACR has with members of the technological community. A final type of consequential changes and activities is linked explicitly to the disruptive emerging technology itself, the NMR. Thus, I define an occurrence as an incident following a three-step scheme (TSC):

1. Any of the ACR's occurrences linked to organizational structure, mission, bylaws, and leadership within ACR (internal actions).
2. Any of the ACR's occurrences related to the relationship that the ACR has with other members of the technological community. In particular, changes or activities linked

to incumbent organizations, new organizations, research teams, governmental agencies, and other professional associations are relevant here (external actions).

3. Any of the ACR's occurrences explicitly linked to NMR devices (technology-centered actions).

Data Gathering & Reliability Check

With the raw data conceptually defined, it was logical to move to other key decisions within the collection of raw data. The first challenge to be addressed was related to the delimitation of the data collection. I decided to let the data collection process determine the precise limits of my efforts. However, as the starting point of the formal acquisition of data in the form of the recording of incidents, I chose to set it at the moment the organization formally became aware of the existence of the new, emerging technology. In other words, I started the recording of incidents in 1979, when the technology was first encountered in the documents I reviewed within the ACR. The end point in the effort was less certain at the beginning of the data-gathering effort, because it was difficult to imagine what kind of proxy one could define as the end of an adaptation process (depending on one's own ontological posture, one could even argue that there is never an end to those type of processes). Thus, I decided to let the end of the collection remain undefined and let the process itself inform me when the activities more directly linked to NMR devices faded.

However, it is important to note that my knowledge of the history of the diagnostic medical imaging community and my initial comprehension of the emergence and development of the NMR devices (described in detailed in the next chapter) bound my initial searching plan. In other words, early in the process I decided to read, peruse, and collect as many documents as I could from the ACR archive for the period between 1965 and 1990. Figure 12 helps to evaluate how this period fits within the overall history of the evolution of the community and the technologies embedded in it. Nevertheless, it is important to note that a deeper understanding of the evolution of NMR devices (described in the next chapter) is critical to fully grasp the strength of this decision.

As previously mentioned, the type of documents considered from the ACR archive is diverse. I identified multiple annual reports, minutes, technical reports, formal communications between commissions, pamphlets, and other wide-ranging documents. In particular, a monthly publication distributed to all members, named the *ACR Bulletin*, became, over time, the most important source of information for this gathering effort. These documents turned out to extremely valuable because they were the only ones that were produced and preserved within the archive. Thus, the monthly bulletins allowed me to have a constant recount of the history of the organization, as it was unfolding. Additionally, considering that this publication was the vehicle that the leaders of the organization used for informing members about all the critical developments in the world of radiology and about the most relevant activities of the organization (Linton, 1997), it turned out to be an ideal source to anchor and follow the critical actions of the organization.

After skimming through the most relevant documents three times and considering the choices described above, I collected a large set of relevant images from the entire set of documents for the 1965–1990 period. This gathering effort had as an outcome a collection of approximately 4,000 images. Although I tried to be as thorough as possible, it is likely that I missed some important document or occurrence by limiting the amount of the information available to these 4,000 images. In addition, it is regrettable that no one else could provide a different perspective in the selection of this set of images. The reasons behind this are twofold. First, the contractual conditions granting me permission to collect data were so constraining that asking permission for another person to peruse the archive could seriously compromise the likelihood of receiving permission for collecting my data all together. Second, due to the lack of robust financial funding to cover the expenses for traveling to the archive (from Champaign, IL to Chantilly, VA), it would have been exceedingly unlikely to cover the travel expenses for a second researcher. I actively tried to minimize the consequences of this drawback on my collection effort in two ways. First, I tried to triangulate the existence of the occurrences derived from the images with alternative sources (mainly by relying on another 4,000 images coming from the monthly-published industry journal *Diagnostic Imaging,* see Table 3). Additionally, I took advantage of a later trip to the archive to double-check some key periods and review again the documents available to make sure that I had not missed any significant information.

With the collection of images at hand, a research assistant and I separately followed the three-step scheme to distill incidents from the images. We started with a sample of 100 images each (corresponding to the year 1980), and, while the research assistant identified 33 incidents, I found 37 incidents (approximately 90 percent inter-rater reliability). The key difference between the assignations of incidents is explained by the fact that I considered that an image could contain multiple incidents, whereas the other coder assumed that my interpretation could not happen by definition. Once we clarified that mismatch, we reviewed another 100 images (for the year 1981), and we both indentified 40 incidents.

After considering these changes, I completed the laborious process of collecting incidents and classifying them. It is important to note here that, following the suggestions of scholars who have used this methodology on multiple occasions (Grazman and Van de Ven, 2000), I also gathered, along with the bracketed information about each incident, other important information. Each incident was part of a sequence file with: (1) date of occurrence, (2) the actor(s) involved, (3) the action or behavior that occurred, and (4) the source of the information. One needs to keep in mind that this sequence of incidents was constructed with the objective of establishing the base for ulterior analyzes and recoding into higher-order constructs (i.e., events). Following the three-step rule described before and bounding the collection of incidents to those occurring between August of 1979 and December of 1988 (the justification behind these two particular stopping points will be discussed in depth in the data analysis section), the number of incidents identified ascended to approximately 400, with an annual average of close to 40 events.

Phase II: Event Coding and Initial Exploration

Once the incident sequence file was created, arguably the most challenging task had to be undertaken: the identification of events. Incidents and events are qualitatively different types of information, and, according to the precepts of this methodological approach, their relationship is not a simple one, nor one set a priori. Whereas incidents are factual occurrences, events are conceptual interpretations made by the researcher(s) conducting the investigation. Thus, identification of events from the sequence of incidents implies a move "across level of abstraction between indicators and theoretical constructs"(Poole *et al.*, 2000: 140). For this reason, researchers with vast experience in this approach emphasize the need for a careful transition from incidents to events.

At least three options are recommended when going through this process (Abbott, 1984; Poole *et al.*, 2000). The first and most straightforward option "is to give all indicators of an event equal weight, thus, starting an event when the first indicator is observed, continuing until the last occurs […] This event would then stretch across a number of incidents" (Poole *et al.*, 2000: 141). A second strategy is "to make judgments concerning whether indicators signal an event on a case-by-case basis. This is a common approach in historical studies where the researcher establishes whether an event occurred by considering the indicators in context. The researcher uses her or his judgment and contextual knowledge to determine the occurrence and duration of events" (Poole *et al.*, 2000: 141). A third approach is to "use indicators as some measure of central tendency, such as the median occurrence of an incident" (Poole *et al.*, 2000: 142). Although the choice depends on the project, data, and the researcher in charge, one option suggested by these scholars is to balance options one or three with strategy two, given the potential advantages that the consideration of contextual issues could bring to the mere use of "objective" rules.

Given my lack of experience with this methodology, I chose, as the initial exploratory coding, a strategy close to option one, based on three categories built into my definition of an incident. These categories were developed from previous work spent studying organizational adaptation that allowed me to begin thinking about the responses of the ACR through the lenses of these previous frameworks. Thus, I classified incidents as events according to their three natural groupings (ACR's internal and external actions and ACR's actions linked to technology) derived from the three-step rule defining incidents.

With this exploratory coding system at hand, a research assistant and I coded a sample of 100 incidents in order to test the reliability of this scheme. We agreed in all the cases for the technology grouping (this seems logical considering that if the word *NMR* was part of the article or document under review, the incident became automatically a technology one). For the other two groupings, inter-rater reliability was approximately 80 percent. Although this reliability level seems adequate considering the more complex decision-making process needed to define what is internal or external for a professional association like the ACR or the possibility of multiple interpretations, the review of our disagreements allowed us to refine our comprehension of the scheme.

An example of three random events identified within the incident sequence file can be observed in Table 4. Table 5 and Figure 13 depict how these types of event evolved over time. Although a deeper analysis of these and other tables and figures will be presented in the next section, it seems important to stress here that events explicitly linked to the disruptive technology (NMR devices) were not the most frequently found, accounting on average for nearly 12 percent of the total incidents identified. In other words, these types of events were not, in general, the ones that dominated the agenda of the ACR, at least in terms of their frequency. How can this be the case, knowing how challenging and threatening the emergence of this new technology was? Should not we expect a hefty level of activity by the ACR linked to NMR devices? The next section delves into this and other related questions when further analyzing the data gathered on the actions of the ACR in response to the emergence of NMR devices.

CHAPTER V: FINDINGS AND THEORETICAL MODELS

Before discussing the findings on the response of the ACR to the emergence of NMR devices, it seems important, considering the evidence supporting the co-evolution of technologies and communities (Fatas-Villafranca, Sanchez-Choliz, & Jarne, 2007; Rosenkopf & Tushman, 1998a; Van de Ven, 1993), to summarize the creation, development, and commercialization of NMR devices. This summary will help to differentiate the NMR devices and the images they produce from previous technologies within the community under study. Perhaps, more importantly, this summary will show why nuclear magnetic resonance (NMR) devices can be considered a disruptive technological discontinuity and how they threatened key “jurisdictional claims” (Abbott, 1988) of radiologists, and therefore, threatened the identity and existence of the ACR.

NMR Devices: Creation, Development, and Commercialization (1936–1988)

Considering that the main objective of this investigation is to understand the response of the American College of Radiology to the emergence of NMR technology, it seems logical to review in detail how this technology was conceptualized, linked to medical imaging, tested, and eventually commercialized. However, creating a detailed event-by-event historical reconstruction of the entire process of the development of this technology goes beyond the scope of this investigation (see Grant & Harris, 1996; Joyce, 2001, 2008; Kevles, 1997; Kleinfield, 1985; Mallard, 2006; Mattson & Simon, 1996; Mitchell, 1988; Tansey, Christie, & Reynolds, 1998 for different aspects of this developmental process). Thus, I focus on describing five critical stages of this process: from the theorization of the NMR phenomenon to the final commercialization success. The upcoming subsection details the first of these stages.

1. NMR Theorization and Early Application (1936–1969)

Although scientists have studied magnetic properties of matter for quite a long time, the existence of the NMR phenomenon was theoretically predicted and later tested in laboratory only in the mid-20th century. In 1936, Dr. C. J. Gorter theorized the existence of this phenomenon (Heilbron, 1962). By 1946, two American scientists, Bloch (Stanford) and Purcell (Harvard), working independently, demonstrated the existence of NMR (Steinberg & Cohen, 1984). For this discovery, they were awarded jointly the Nobel Prize for Physics in 1952. Since then, scientists (especially chemists) have routinely used this phenomenon to study the molecular structure and dynamics of small samples.

To understand the phenomenon it is important to remember that, first, atoms constitute matter inorganic and organic, and each of these atoms is, in turn, made up of particles' denominated protons (located in the nuclei of the atom) and neutrons (located beyond the nuclei). Second, certain *nuclei* contain an odd number of protons and neutrons, each of which possesses an intrinsic angular momentum called "spin" (Steinberg & Cohen, 1984). Because nuclei are electrically charged, their spin generates small magnetic fields, and then they could be conceptualized as *magnetic* atoms that would be susceptible to be used in experiments relying on the NMR phenomenon. For this reason, NMR experiments are possible in matter with a surplus of atoms such as $^{1}Hydrogen$, $^{13}Carbon$, $^{19}Flourine$, $^{23}Sodium$, and $^{31}Phosphorus$. Supplying energy (radiofrequency) of an appropriate rotational frequency will stimulate the nuclei from a lower energy level, E_1, to a higher energy level, E_2. If the energy is turned off after the nuclei have been raised into the higher energy level, the excited nuclei drop back to level E_1—they relax. However, the radiofrequency causes the nuclei to spin in sync in the same direction at the same time, a movement "in phase" (Mattson & Simon, 1996). In the process of relaxing, the nuclei re-emit the energy they had initially absorbed. If this energy is repeatedly applied, the nuclei will oscillate, or *resonate* back and forth between E_1 and E_2, alternately absorbing and emitting energy (Steinberg & Cohen, 1984). It is based on this mechanism that the phenomenon takes its name: ***N***uclear (nuclei-centered), ***M***agnetic (magnetic nuclei), ***R***esonance (oscillation caused by alternate external exposure to specific radiofrequency energy).

Because the NMR signals emitted by the nuclei are extremely weak, atoms must be present in sufficient concentration in order to produce an NMR signal that is strong enough to be captured by the equipment. In other words, the signal captured by any NMR equipment is proportional to proton density but also depends on at least two other parameters (Steinberg & Cohen, 1984). These two parameters are tightly linked to how nuclei resonate: T_1, called longitudinal, or spin-lattice, relaxation time, and $T_{2,}$ called transversal, or spin-spin, relaxation time (Mattson & Simon, 1996). T_1 measures the amount of time the protons take to return to their initial energy level. In contrast, T_2 corresponds to the amount of time the nuclei take to get out of "phase" or to point again in random directions (Joyce, 2001). Any single NMR measurement depends on the density of nuclei, T_1, $T_{2,}$ and on the particular radiofrequency pulse sequence employed to excite the nuclei of the matter under study. What we know today about the phenomenon is the product of incessant work by a myriad of physicists, from Purcell and Bloch, to Nicolas Bloembergen and Erwin Hahn, who theorized and tested their hypotheses. However, from the early 1950s to the late 1960s, the chemists would be the ones expanding the use of this technique by relying on previous research demonstrating that each molecule has its own unique resonance frequency (Joyce, 2001). This property allowed the chemists to use NMR as a way to identify the types of molecules present in a particular substance and to analyze the exact makeup of complex substances (Joyce, 2001).

Beyond university laboratories running pure scientific investigations, Varian Associates of Palo Alto, California, capitalized on this phenomenon by creating the first industrial device, called an NMR spectrometer, because they showed “a spectrum” of frequencies, relying on a license they obtained from Stanford University. These instruments detected one signal for an entire sample and displayed it as a set of frequencies with no information about the location of the resonating nuclei, usually consisting of inorganic complex substances (Mitchell, 1988). However, by 1955, John D. Roberts, a chemistry professor at California Institute of Technology, started using a Varian NMR spectrometer to study organic compounds—small slices of tissue of once-living creatures fitted in 5 mm test tubes (Kevles, 1997). In 1959, Jay Singer, at the University California–Berkeley measured blood flow rate in a mouse with a Varian NMR spectrometer, proving that the technique was not necessarily harmful to living organisms (Kevles, 1997). After this experiment on a living organism, some scientists considered the application of this technique on human beings and began to imagine clinical applications. The following subsection details those initial explorations of how NMR was applied to clinical medicine.

2. Early NMR Application to Medicine: A Contested History of Its Origin (1969–1975)

Although the history of the theoretical development and the initial applications by chemists has generated little controversy, the history of the application of the NMR phenomenon to medicine, and particularly to diagnostic imaging, is quite controversial. However, notwithstanding the source one relies on, two critical actors are always singled out: Dr. Paul Lauterbur, a chemist, and Dr. Raymond Damadian, a research physician.

Damadian is recognized by many as the first researcher to link NMR with clinical medicine. He was a medical doctor from the Albert Einstein Medical School at Yeshiva University in New York and completed his postdoctoral work at Harvard before joining the faculty at the Downstate

Medical Center. In the late 1960s, Damadian had become intrigued with a controversial theory of biologist Gilbert Ling's, who argued that when a cell becomes cancerous, it loses its structure and the capacity to distinguish between sodium and potassium ions, thus filling up with water. This theory implied that there ought to be major differences in the water content and structure of normal cells compared to cancerous cells (Blume, 1992). Damadian tried to test those differences by using a NMR spectrometer in June of 1970. He tested six tumor-infected rats in the laboratory of NMR Specialties, a laboratory in a suburb of Pittsburgh, where he sacrificed the rats and removed pieces of their tumors through a NMR spectrometer, evaluating T_1 and T_2 readings (Kevles, 1997). These readings supported his expectations, showing that cancerous tissue has a lower degree of organization and lower water content than normal tissue. He later summarized these results and their meaning in an article that he submitted in October 1970 and which was published in March 1971 in the prestigious journal *Science.* The title of the article was "Tumor Detection by Nuclear Magnetic Resonance," and, beyond providing evidence that could be interpreted as supportive of Ling's theory, it was used by Damadian as indicating that NMR "methods may be used to discriminate between two malignant tumors and a representative series of normal tissues. *The results suggest that this technique may prove useful in the detection of malignant tumors*" (Damadian, 1971:1153 emphasis added). Additionally, he finished this paper by noting, "The possibility that NMR might be used for rapid discrimination between benign and malignant surgical specimens was also considered. Relaxation times for two benign tumors were distinct from those of malignant tissues, and were the same as those of muscle"(Damadian, 1971: 1153).

Those who have studied the evolution of NMR devices in detail have stressed at least three strong consequences of the publication of this article. First, nowhere did Damadian mentioned using “NMR for extracting an image” (Kevles, 1997: 178). Second, other researchers captured the wide-ranging consequences of these results and re-energized their own research efforts by trying to reproduce and expand the discoveries triggered by this paper. This is particularly important given that President Nixon, “through the passage of the National Cancer Act, had declared his intention to spend a billion dollars a year to try once and for all to slay cancer” (Kleinfield, 1985: 32). Third, based on the second quote presented above, Kevles argued that Damadian saw these results as a way of detecting “cancer in excised tissue,” which until then was a pathologist’s job, not that of radiology (Kevles, 1997: 178). In fact, Dr. Michael Goldsmith, a key member of the team of post-graduate assistants that Damadian nurtured at the Downstate Medical Center in Brooklyn, New York, noted that their

> “work became […] controversial, [and thus], too hot for the journals to handle politically […] At first the criticism started to coalesce around the argument that, yes, you can determine the difference between cancerous tissue and normal tissue, but that’s not the question. The question is, Can you determine the difference between cancerous tissue and other abnormal pathologies? There was very little data by anyone on this. Well, my feeling is you have to start on the ground floor. The ground floor was whether you could determine the difference between cancerous and normal tissue. I think ***there was a lot of resistance from pathologists who had a vested interest in the current technology***. They did not want anything new unless it was handed to them in final form in a platter. Academicians in a sense are a lot like lawyers-not that lawyers are not my favorite people. Very often, they view their role in society as shooting holes in an idea rather than coming up with an honest test of the idea. ***They were saying that NMR was not hundred percent accurate, and pathology was one hundred percent, which is not true anyway***.” (Kleinfield, 1985: 191 emphases added)

Internally, the strong reaction that this paper had in academic circles gave Damadian and his team new strength to continue delving into the details of these discoveries. That same spring, as part of a public relations effort by the medical center, a freelance science writer, Ed Edelson, was hired to write a story about Damadian’s work. In an article entitled “Basic Research Leads to Radio Signals from Cancer Tissue,” the reporter noted that “Already, Dr. Damadian is planning to build a much larger nuclear magnetic resonance device, one that will be big enough to hold a human being. That machine, Dr. Damadian believes, will prove that nuclear magnetic resonance (NMR) is the tool that doctors have been looking for in their quest for a method of detecting cancer early, when treatment is most effective" (Kleinfield, 1985: 34). This minor article would be, and it is even today, at the center of the intellectual fight with Damadian's nemesis, Dr. Lauterbur, because, according to Damadian, it would be the first time a "method was published to produce the volume localization needed for scanning the body by NMR" (Kleinfield, 1985: 34).

Spatial localization was a critical concept, because without it the signals from different parts of the body would overlap and create useless mass. Damadian's solution for this problem, a technique he coined FONAR (an alternative acronym that stands for field-focused nuclear magnetic resonance), relies on shaping the magnetic field across the entire sample (a saddle-shaped field) "to construct a small resonant window at the particular point of interest. The radiofrequency exciting the nuclei would correspond to the field strength at the nadir or saddle point of the magnet. Hence, NMR signals would be detected only from this point. Nuclei in other parts […] would either be resonating at a different frequency or would be situated in areas where the field strength was so steeply graded that too little signal would be generated to be detected"(Kleinfield, 1985: 35).

By March of 1972, Damadian applied for a patent for his creation under the title "Apparatus and method for detecting cancer tissue" and announced in a press conference that "he would build an NMR machine large enough to map an entire human body for the presence of malignancies" (Kevles, 1997: 178). Notwithstanding all these efforts, Blume argues, "Damadian had not envisaged transforming the NMR signals to images"(Blume, 1992: 195). Filling that gap is where Damadian's nemesis will become a critical figure in the development of NMR.

Dr. Paul Lauterbur was exposed initially to NMR technologies while observing the operation of a Varian NMR spectrometer while working at Dow Chemical during his graduate studies in the early 1950s. He actually operated one of these devices a few years later, while working at the Military Medical Laboratory (Kevles, 1997). In 1963, he joined the faculty of the State University of New York at Stony Brook. In the summer of 1970, and based on his expertise with these devices, he was chosen as president and chairman of the board of a struggling and insolvent company, NMR Specialties. It was within this company where Damadian ran his first experiments with rats in the late 1970s. In fact, Lauterbur was present while Damadian ran some of his experiments, and, in an interview with Kevles in 1992, he asserted that, as he watched the procedure he had thought that "there had to be a better way of using NMR clinically than excising tumor samples" (Kevles, 1997: 180). For this reason, he dismissed Damadian's idea because it meant putting NMR machines into operating rooms to do on-the-spot NMR biopsies (Kevles, 1997). However, he kept thinking about this phenomena and in September of 1971, he finally imagined an exact way of localizing from where NMR signal came by using magnetic field gradients:

> If a magnetic field varies from one point in the object to another […] the resonant frequency which is directly proportional to the strength of the magnetic field will vary the same way. So, for example, if [one] made a magnetic field increase a little from [a] left ear to [the] right ear, the left ear would have one resonance frequency and the right ear would have a different one. With that in mind, [Lauterbur] plotted out the resonance frequencies and deduced that he'd see a little ripple on one side for one ear and a little ripple on the other side for the other ear. That would give one dimension of information by reducing all the complexity in his head between this two ears to a single trace […] He could get a full image by applying magnetic field gradients in different directions[…] This was the beginning of what is now known as one-dimensional imaging. He could translate those single points of data from different places along the magnetic gradient into *spatial information* (Kevles, 1997; 180/181 emphasis added)

Lauterbur called this technique *zeugmatography*, from the Greek "joining together," given that he was joining together a gradient magnetic field and the radiofrequency that corresponds to it in a single image (Kevles, 1997). It is important to note that this creation was made in late 1971, almost a year before the public debut of EMI's CT scanner. Kevles argues that Lauterbur's approach was "a quantum leap beyond the kind of image Damadian was getting at this time, which had no spatial dimension"(Kevles, 1997: 181).

After failing to patent this idea due to institutional problems with the relationship between SUNY and NMR Specialties, Lauterbur submitted his idea as a conceptual paper in October 1972 to *Nature*, a leading British scientific journal, where it was finally published in March 1973 under the title "Image Formation by Induced Local Interactions: Examples Employing Nuclear Magnetic Resonance" (Lauterbur, 1973). Although it took a couple more years for the introduction of the two-dimensional NMR, a creation of Richard Ernst's in 1975, Lauterbur's trailblazing article gave him the recognition of a large portion of the scientific community, and ultimately that was the reason why he was a co-recipient of the Nobel Prize in Physiology or Medicine in 2003 (Filler, 2009).

3. NMR Imaging Prototype Race: A Race on Both Sides of the Atlantic (1975–1979)

The influential investigations by Lauterbur and Damadian provided a fertile ground from which a myriad of other researchers quickly extended different discoveries and creations. In particular, four research groups located in the United Kingdom (Tansey *et al.*, 1998) and two group of investigators working in the United States critically shaped the development of NMR devices for clinical use in medicine, given their own special approaches, backgrounds, and interests (Kevles, 1997).

The first research group in the United Kingdom was based at the University of Aberdeen, Scotland, and was led by Dr. John Mallard. Mallard was a professor of medical physics who was influenced by Damadian's work (Mallard, 2003) and started his research on NMR application for clinical diagnosis in early 1970. This new research focus was not far from his previous efforts to characterize tissue by using a recent laboratory tool, known as the electron spin resonance (ESR), which had resulted in his article published in the journal *Physics in Medicine and Biology* (Hutchison, Foster, & Mallard, 1971). The previous expertise gave this group an initial advantage, which materialized after the publication of Lauterbur's paper in *Nature*. With resources of his own department, Mallard and his team (Blume, 1992) constructed a proton-focused (measuring the resonance of hydrogen nuclei) NMR device with a permanent magnet (25 MHz) and a working space of approximately nine inches (large enough to house a mouse), and using Lauterbur's method, they quickly published a crude image of a mouse (Hutchison, Mallard, & Goll, 1974).

Two other research teams were homed in different departments at the University of Nottingham. One was led by Professor Raymond Andrew (Blume, 1992), who, in conjunction with an American postdoctoral fellow, Waldo Hinshaw, took an aggressive research program that started by creating new mathematical ways of generating images without complex data processing (Hinshaw, 1974). Later, they produced the first image of a human wrist, publishing it in *Nature* in December 1977 (Hinshaw, Bottomley, & Holland, 1977). Figure 14 shows the picture included in that article as an additional way of assessing the progress in terms of quality and other characteristics of the image produced by the early NMR devices.

Peter Mansfield, a physicist, led the second team located at Nottingham. He was unaware of Lauterbur's and Damadian's work when in 1973 he published his first paper on NMR diffraction in solids (Mansfield & Grannell, 1973). After reading their work in 1974, he decided to refocus on NMR imaging of the human body and quickly created and patented the method for selectively exciting and defining a slice (Garroway, Grannell, & Mansfield, 1974). In 1977 they obtained the image of a human finger (Mansfield & Maudsley, 1977), and in 1978 the cross-section of an abdomen (Mansfield, Pykett, & Morris, 1978) by using a new technique in which an electromagnet with a horizontal field was excited later by echo-planar fast pulse sequences (Mallard, 2003). All these significant contributions were later part of the justification for Mansfield to become, with Lauterbur, the co-recipient of the Nobel Prize in Physiology or Medicine in 2003 (Filler, 2009). Figure 15 shows the pictures included in those two articles, showing NMR images of (a) a finger and (b) the cross-section of an abdomen as an additional way of assessing the progress in terms of quality and other characteristics.

Finally, the highly successful industrial incumbent EMI was also part of the early development of NMR imaging by its support of a research team led by Dr. Young. This team was the first to offer a NMR image of a human head in 1978 (Young & Clow, 1978). Figure 16 shows the picture included in that article as an additional way of assessing the progress in terms of quality and other characteristics of the image produced by the early NMR devices.

In the United States there were, at this point in the development of NMR, at least two active academic research teams participating in this race, although they seemed, for the most part, to have lost the first round of the race. The first and more active group in the early development of NMR applications to medicine was led, as noted before, by Dr. Damadian himself. The second group was homed at the University of California–San Francisco (UCSF) and was led by Leon Kauffman, a physicist, and Dr. Alexander Margulis, a professor of radiology (a key actor from the ACR perspective). The critical difference between these two groups was that Damadian's group was the leading force in many of the early developments, while the UCSF's group was a late entrant, starting in late 1975, and thus, their influence in the development of the technology was quite different in terms of timing and content (Grant & Harris, 1996).

Particularly influential in this period, Damadian's team continued working at a fast pace but ran into multiple problems for lack of research funding, a problem that continuously threatened their research (Blume, 1992). However, in 1974 these problems were alleviated when Damadian was finally awarded the patent for his NMR scanning technique, and he received a small grant from the National Cancer Institute. They continued working with the equipment they had and published in *Science* in 1976 a cross-sectional NMR image of the thorax of a live mouse (Damadian, Minfoff, M., Stanford, & Koutcher, 1976). Figure 17 shows the picture included in that article as an additional way of assessing the progress in terms of quality and other characteristics of the image produced by the early NMR devices.

With some funds he collected through his family contacts, Damadian started the construction of the first whole-body NMR device, a machine they coined "the Indomitable" (see Kleinfield, 1985 for the complete history of its creation). This was a remarkable machine, now conserved at the Smithsonian Museum (see Figure 18). This device was so special that they had to build a superconducting magnet (that could produced a 5,000 Gauss magnetic field) themselves. Notwithstanding all the problems and delays that including this subsystem caused, the magnet itself was a critical feature considering the future clinical application of these devices and the improvement in the resolution of the images that having a strong magnetic field could produce (Kleinfield, 1985). They finished the construction of this machine in May 1977, obtaining the first successful image of a human thorax (the thorax of Damadian's assistant, Dr. Lawrence Minkoff) on July 3, 1977, after 4 hours and 45 minutes of operation (Blume, 1992; Kleinfield, 1985). Damadian and his team soon after developed a manuscript documenting their findings and published it in December of 1977 in the second-tier journal *Physiological Chemistry and Physics* (Damadian, Goldsmith, & Minkoff, 1977). Figure 19 shows the picture included in that article as an additional way of assessing the progress in terms of quality and other characteristics of the image produced by the early NMR devices. It is important to note that the images of these devices were in a range of colors.

The improved quality of images and reduced uncertainty regarding the potential of this new technology (their possible use in the hospital became clearer) was not disregarded by key incumbents in diagnostic medical imaging (Blume, 1992). Soon after incumbents had observed some of these key improvements, they decided to become actively involved in the technological race that could determine who would reap the profits of this new technology.

4. Incumbents Enter the Race (1977–1982)

As described by one of the academic investigators leading the research on NMR devices, the reaction to the first NMR human images was frenetic with "multinational medical imaging companies" showing great interest in the work and even attracting key members of these research teams (Mallard, 2003: 361). One of the first industry incumbents to become interested in the new NMR devices was NV Philips (a Dutch firm). This firm developed within their own electronic R&D division a 0.15 Tesla (150 Gauss) resistive magnet and, by 1978, they had transferred the project to their medical division, where financial support from the German government was used to test and improve the device (Mitchell, 1988). During 1977, Bruker AG (a German firm), with the help of a postdoctoral fellow from Andrew's research team, built a 0.13 Tesla resistive magnet system to start their research program (Mitchell, 1988). Siemens started a research program in Erlangen in 1977 (Mitchell, 1988), and by 1978 it was able to hire one of Mansfield's research team members, Andrew Maudsley, and receive financial support from the German government (Mitchell, 1988).

Pfizer, a pharmaceutical firm that had entered the imaging sector by licensing a whole-body CT a few years before, became involved in the development of NMR devices by funding the research of the UCSF research team. EMI, another diversifying firm relatively new in the imaging community but enjoying the great success of its CT scan units, entered the NMR race by supporting, along with the British government, a research program led by Ian Young, an engineer (Mitchell, 1988). This research program was clinically evaluated within London's Hammersmith Hospital, and by 1978 they had published some images with a resistive magnet device they had built (Young & Clow, 1978).

General Electric Company, one of the leaders in the imaging community, started its own in-house research program in 1978. By 1980, GE was able to hire key researchers from the Aberdeen group and from Nottingham (William Edelstein and Paul Bottomley, respectively) to establish a stable R&D facility in New York. This group started working on a 0.12 Tesla resistive magnet but quickly switched to a superconducting magnet design (Mitchell, 1988). Johnson & Johnson acquired Technicare Corporation, a company with no NMR experience but with a strong research base and key distribution system (Mitchell, 1988). Technicare set up an in-house R&D group but also supported the research program of Waldo Hinshaw at the Massachusetts General Hospital. In 1979, Hinshaw moved to Technicare's Cleveland facility (Mitchell, 1988). Thomson-CGR Medical Corp also started a research program by relying on a resistive magnet of 0.15 Tesla during 1979.

With all this activity by incumbents, different researchers also tried to appropriate some of the value they had created as a way of infusing new funds to be able to compete with the large corporations that were actively trying to win the race to develop the first device that could be used commercially. James Carolan, a postdoctoral student of Andrew's, set up his own company in California in late 1975, Nalorac, and a couple of years he sold it to Nicolet, a diversifying firm. Williams Genthes of the Medical School of Wisconsin created Metriflow Inc. Perhaps the most successful in the end was the company founded by Damadian, incorporated back in 1978, a company he named Raanex II, trying to improve his position to negotiate with Johnson & Johnson or General Electric. Later, he changed the name of this company to FONAR (the name of its original patented method to obtain NMR readings) and created a series of NMR devices beyond his original "Indomitable." Even the research team at Aberdeen, led by Dr. Mallard, actively tried to capitalize on their experience with these new devices by establishing an alliance with the Japanese corporation Asahi Chemical Co that allowed them to build a second-generation NMR device (called Mark 2). By early 1982, the team had incorporated into M & D Technology, Ltd (Mallard, 2003), a company that failed in 1985 "largely due to under-capitalization" (Mallard, 2003: 362).

During this period, as one would expect within a "ferment era" as described by Tushman's technological evolution framework, all these different academic and corporate research and development teams competed with each other to present the best possible device. However, the very concept of "best" was under debate, with two critical issues at the heart of the debate. The first argument was whether NMR devices were going to be used only to create images or also to acquire information about cell-level activity by interpreting the spectra that the nuclei of the cells produce when they are subjected to magnetic forces. This use is referred to as *in vivo* magnetic resonance spectroscopy (Mitchell, 1988). The second issue centered on the type of magnet to be used and, consequently, on the strength of the uniform field created. Some groups used permanent magnets, some employed resistive magnets, while still others utilized superconductive magnets from 0.2 to 1.5 Tesla. Each of these types of magnets has their strengths and weaknesses, and none of these teams knew beforehand which combination would become the most accepted. In the end, the first unit that received an investigational device exemption from the FDA (the agency bestowed with powers to regulate medical devices from 1976) was set up outside a R&D lab and was a system created by FONAR. The QED 80 model (permanent magnet producing a 0.04 Tesla magnetic field) was housed in a private clinic in Cleveland (Mitchell, 1988) in late 1980.

5. From NMR Pre-Market to MRI Hegemony (1981–1988)

NMR producers, following FONAR's sale to the clinic in Cleveland, followed suit and were also able to get an investigational device exemption from the FDA to sell the devices they produced. Most of the early sales were to university hospitals and generally with deep discounts over the list prices (which ranged from $500,000 to $1,000,000). Each commercialized device was built with different types of magnets and different field strengths. Mitchell (1988) groups these early devices depending on the strength of the magnetic field produced by the magnet in "low, mid and high" field systems: with low-field systems with field strength below 0.12 Tesla, mid-field devices ranging from 0.12 to 0.6 Tesla, and high field with a permanent magnetic field above 0.6 Tesla. In 1981, U.S. sales were quite low (only three devices had been sold), but they started to pick up in the following year with seven devices sold in 1982. Most of the 10 devices sold between 1981 and 1982 could be characterized as mid-field systems (seven), with high field systems being the second most popular configuration. Sales overseas were also small with five units sold in the rest of the world (two in Japan, one in Mexico, and two in Europe) (Mitchell, 1988).

The UCSF research group was the second research team able to produce a system that could be commercialized, selling their first unit to the UCSF Radiologic Imaging Laboratory in 1981.

This was a major accomplishment for this group, considering its relatively small size and resources. Because of their success, in August of 1981 Diasonics Inc., an ultrasound manufacturer, acquired the commercialization rights for the devices produced by this team (preempting Technicare) by paying $ 2.2 million to Pfizer, $500,000 to UCSF, and giving stock options to the UCSF researchers. Diasonics also committed to pay some royalties to UCSF. Just three months later, they shocked the imaging community at the November meeting of the RSNA by showing the best NMR images that anyone had seen. Soon after, they placed their 0.35 Tesla superconducting magnet unit in the UCSF radiology department (Mitchell, 1988).

Bruker placed a 0.13 Tesla resistive system at the Baylor College of Medicine and at a University Hospital in Japan. GE sold a 0.15 Tesla resistive unit to the University of Pennsylvania, while M & D housed a 0.08 Tesla resistive system (Mark 2) in the Grampian Health Board in the Royal Infirmary in Scotland (Mallard, 2003). Technicare, in contrast, produced a multitude of NMR device models until a clearer standard emerged, placing a 0.15 Tesla resistive unit at the Massachusetts General Hospital in 1981 and a 0.30 Tesla superconducting system at the University Hospital in Cleveland in 1982 (Mitchell, 1988).

During these first two years of commercialization, EMI also abandoned the NMR field—as a reaction to EMI’s overarching corporate strategy—and sold all its development and research to the British radiological leader GEC PLC, General Electric Company, no relation with the American corporation GE (Mitchell, 1988). Under this new ownership, the developers of NMR were able to sell two units in Great Britain, a 0.15 Tesla resistive unit to the Nottingham Hospital and 0.15 Tesla superconducting unit at the Hammersmith Hospital in London (Mitchell, 1988). This last unit came to be especially important in the overall development of the NMR devices, because it was one of the first to take advantage of the strengths of its superconducting magnet to create high-resolution images. This magnet “gave greater signal strength, and enabled finer spatial resolution to be obtained in the images” (Mallard, 2003: 362). These “supercons” (Mallard, 2003: 362) ended up winning the design race, in spite of their prohibitive initial cost and great operative expenses.

By 1983, the dynamic of the industry had changed significantly, with NMR devices not going to hospitals but rather being bought by private clinics, set up by joint ventures between doctors and hospital executives (an arrangement aimed to circumvent federal regulation of hospital expenditures), and American buyers preferring the higher-resolution superconducting systems (Mitchell, 1988). That year, Technicare was the sales leader, placing 16 units, while Diasonics placed five (all of them superconducting), and the next three manufacturers combined selling only seven systems (GE, Bruker, and FONAR) (Mitchell, 1988). Two international firms also sold units in the United States during 1983. Philips sold a unit to the Columbia-Presbyterian Hospital in New York, with Elscint (an Israeli company) and Siemens placing four superconducting units (Mitchell, 1988).

In 1984, the NMR demand, and consequently the sales, exploded, especially after a key uncertainty over the new devices was resolved by a series of FDA resolutions. The FDA approved for non-investigational use (premarket approval) systems produced by Diasonics, Technicare, FONAR, GE, and GEC (head and neck). Additionally, the FDA approval, or lack thereof, also significantly affected the GEC body system and the Philips devices, hampering their sales (Mitchell, 1988). According to Mitchell (1988), more than 100 units were placed in the United States in 1984, with sales close to $120 million. Almost 90 percent of those systems had a superconducting magnet, with a balanced split between mid- and high-field units. GEC, Nalorac, and Technicare all introduced superconducting systems, although Siemens and GE were the main winners of this trend toward supercons, placing combined orders for 40 systems (Mitchell, 1988). Sales outside the United States, mainly in Europe and Japan, were significantly lower, with combined sales totaling less than 40 systems in the same year.

From 1985 to 1988, sales grew consistently—from 200 in 1985 to a figure well surpassing 300 units (most of them housed outside hospitals) and sales surpassing the $500 million level by 1988 (Mitchell, 1988). This continuing demand can be explained in part by the decision in November of 1985 of the Health Care Financing Administration (HCFA) to allow payment for NMR imaging. By the end of 1987, almost 1,000 units were placed in the United States, while the cumulative figure outside the United States merely reached the 100-unit level, with systems mainly located in Western Europe and Japan (Mitchell, 1988). As Dr. Mallard noted (2003: 363), the diffusion of the NMR devices was quite uneven in the world, with most units located on American soil and with only a handful located in the United Kingdom, despite the fact that "the United Kingdom had developed the technology." He explained this phenomenon by arguing that "due to the much greater financial and human resources that the major multinationals could bring to bear, university teams in research laboratories were gradually pushed out of the further development of NMR imaging" (Mallard, 2003: 363/364). By 1988, for the first time in the history of this community, X-ray devices were not the leader in terms of dollars spent on their acquisition; NMR device sales actually matching those spent on X-ray devices. NMR devices had finally dethroned the old king of the medical imaging community. Figure 20 shows two images created by newer NMR devices (by now called MRI scans) to appreciate how the resolution, properties, and quality of the images changed over the last couple of decades. Figure 21 presents two graphs showing the comparative evolution of the market share of the multiple imaging devices, and the total figure in dollars spent on them.

Beyond 1988, demand (and diffusion) of these devices never softened, and by 1996 over 10,000 units were in use with load factors of 16 devices per million inhabitants in the United States, 18 units per million in Japan, and just below 4 systems per million in Europe (with 3 scanners per million in the United Kingdom) (Mallard, 2003). Each year, 2,000 new machines are installed worldwide (representing an approximately 5 percent growth), generating sales well over £1.2 billion (Mallard, 2003). In 2010, the worldwide market of MRI (the new name used to describe the old NMR units) devices is estimated to reach $5.5 billion (Global Industry Analysts, 2008). Comparing this figure with the total market for medical imaging devices: $18 billion, one can realize how important MRI devices have become within the imaging community (Global Industry Analysts, 2008). These data seem to support the idea that over time MRI came to be the dominant technology within the diagnostic medical imaging, so much that Kevles (1997: 200) argued that "by 1994 MRI had become a catch-phrase for all medical scans […] becoming synonymous with all imaging innovation and with its intimations of mystery, new age spiritualism, and high-tech machines."[9]

Now that a deeper understanding of how NMR were created, developed, and adapted to medicine has been acquired, I will begin delving into the analysis of the data gathered on the ACR response to the emergence of this new technology.

ACR Response to the Emergence of NMR Devices: Findings

This stage in the analysis of data is arguably the most difficult to complete, considering that one is trying to reveal the complex patterns of several hundred interrelated events. Although one possible avenue to assess these patterns could be to convert the data gathered into bitmaps and later analyze it with standard statistical techniques, I chose an alternative path by using a two-step "*retroductive*" approach (Poole *et al.*, 2000: 143). I made this choice because the main objective of this investigation is to uncover a process, a detail of actions and strategies used by the ACR to respond effectively to the emergence of NMR devices, and the best way of "examining and articulating processes" (Pratt, 2009: 856) is through techniques that rely heavily on qualitative approaches.

The first step (deductive step) of this retroductive approach included using previous "theory to specify expected categories, which are written into rules" (Poole *et al.*, 2000: 143). As I have described previously, that was exactly what I did in creating or defining incidents in the first place, and later in Phase II (Figure 11) in creating three types of events to match the main overarching categories in the definition of incidents (ACR's internal, external, and NMR-linked actions). However, in this first step, I went further by re-coding each incident into new event categories corresponding to the critical organizational processes or characteristics that previous research had stressed as drivers of effective adaptation. For instance, previous research has stressed the role of leaders (Selznick, 1957 [1984]), relationship with the environment, such as other organizations (Pfeffer & Salancik, 1978 [2003]), and organizational identity (Gioia & Thomas, 1996). I relied on all of these theoretical concepts detailed in the previous chapter and created rules to define the new categories for each of them. These new categories also allowed me to divide the NMR-linked incidents into events linked to internal actions, external actions, and actions linked to the emergence of NMR devices. Tables 6 and 7 show the definitions for each of these concepts.

The second step (inductive step) calls for a refinement and adjustment of the previous coding scheme by sifting through data and "deriving categories from the ground up, using the constant comparative method" (Poole *et al.*, 2000: 143). This procedure relies on repeatedly comparing the data (events) from different sources and different times to discern major themes or processes involved in the effective response of the ACR to the emergence of NMR devices (Gioia & Chittipeddi, 1991). In this case, a critical comparison point was the concomitant evolution of the NMR devices as detailed in the previous section. Figure 22 summarizes this two-step procedure, describing how I moved from the initial categories linked to the three-step rule for identifying incidents to the theoretical constructs used in the final conceptual model.

Once the new themes and categories were developed and compared with the concomitant evolution of the NMR technology, an overarching theoretical model emerged. Figure 23 depicts the model derived from this retroductive procedure. This model presents a conceptual framework explaining the actions of the ACR while responding to the emergence of NMR in *four distinctive stages*. It is important to note here that, in order to appreciate fully the rationale behind the sequence of events uncovered by the data analyzed, it is necessary to superimpose and pay attention to the concomitant evolution of NMR devices. Without a comprehension of the different stages through which NMR devices progressed, it is much more difficult to understand completely the timing and overarching coherence of the actions of the ACR. A detailed explanation of each of these stages within the model presented in Figure 23 follows.

Stage 1: Initial Sense-giving–Sense-making

It has been argued that the emergence of disruptive technologies, particularly those coming from a disjunctive scientific field or knowledge base, are likely to trigger sense-making episodes (Weick, 1979, 1995). New technologies act as "*equivoque* […] something that admits of several possible or plausible interpretations, and therefore, […] subject to misunderstandings, uncertain, complex and recondite […] they make limited sense because so little is visible and so much is transient, and they make different kinds of sense because […many things] that occur within them can be modeled in so many different ways"(Weick, 2001:148).

It is important to assess here to remember that NMR devices emerged from a scientific field that was for the most part dissociated from ionizing radiation, on which the organizational competencies of most community actors rested (Kevles, 1997). Second, the skills needed to operate and interpret the results of the exams performed with these devices were completely different (morphology vs. physiology imaging) to those used by radiologists (Blume, 1992; Joyce, 2008). Indeed, as noted by members of the Office of Technology Assessment in 1984:

> "NMR images are fundamentally different from X-ray or CT images. The later rely on partial absorption and partial transmission of X-ray (linear attenuation) to produce images that reflect differences in the electron densities and specific gravity of the adjacent tissues. Proton NMR images are formed without the use of ionizing radiation and reflect the proton density of the tissues being imaged, as well as the velocity with which fluid is flowing through the structures being imaged and the rate at which tissue hydrogen atoms return to their equilibrium states after being excited by radiofrequency energy (proton relaxation time)." (Steinberg & Cohen, 1984: 4)

Thus, the emergence of these new devices significantly threatened the key "jurisdictional claim" (Abbott, 1988) of 'interpretative expertise" made by radiologists, as well as the main knowledge base of most community members. Taken together, these issues made NMR devices a disruptive technological innovation and, therefore, a trigger of sense-making activity for the members of this technological community.

Awareness

In order to explore whether NMR triggered a sense-making episode specifically for the ACR, one should start by defining when this organization became aware of the existence of these new devices. However, identifying when the ACR, as a social actor or formal organization, became aware of the existence of NMR devices is a challenging task. First, one should question whether social units, teams, or organizations can have "awareness" (Chen, 1996; Chen, Su, & Tsai, 2007; Hambrick, 1981) in the first place, especially considering the frequent calls within organizational studies to avoid anthropomorphizing organizations (Pinder & Bourgeois, 1982). Although a full discussion of this debate exceeds the scope of this investigation, it seems important to note that, because I treated organizations here as interpretative systems (Burrell & Morgan, 1979; Daft & Weick, 1984), awareness could be conceptualized as an organizational-level concept (Chen *et al.*, 2007) or, at least, as the level of the top management team (Hambrick, 1981).

With these two options, I identified first when NMR devices were first named in any of the documents I reviewed in my collection of data. I found that the first reference to these devices occurred in late 1979. Unfortunately, I could not identify the exact date, but the reference linked to this encounter with this new technology was published in December of 1979, summarizing the activities that a subcommittee within a commission, an internal structure of the ACR, had developed in the second half of that year. Within the incident sequence file, this corresponds to incident number six:

> **I # 6 (Dec 1979):** Commission on Equipment & Facilities […]: (7) the *Committee on Emergent Imaging Modalities* received a new modality called Nuclear Magnetic Resonance. The committee conclusion was that *techniques currently available in this modality do not provide sufficient refined image to support a conference at this time*. The committee does suggest that the *college offer support to the radiation study section* of the National Institute of Health for their Conference on nuclear magnetic resonance"

The information contained in this incident provides evidence of three distinctive issues. First, it shows how the ACR proactively prepared for changes in the environment, specifically those related to changes in key technologies affecting the organization by maintaining a committee within a larger commission to actively scan the environment, to act as a key boundary spanner, and to inform the leadership about critical new developments (Scott, 2003; Thompson, 1967; Thompson & Bates, 1957). A second interesting note is how new technologies are evaluated initially by this boundary-spanner group. They explicitly note that the "quality of the images" produced by these new devices are somehow not good enough to imply a more serious evaluation of this new technology. The initial reaction of this boundary-spanner group seems to generate two reactions. First, as noted by technology and institution scholars (Garud & Rappa, 1994; Hargadon & Douglas, 2001; Kaplan & Tripsas, 2008b; Orlikowski & Barley, 2001; Van de Ven & Garud, 1994), in evaluating new technologies, social actors have, at first, no other resources or ways of interpreting than through the lenses of the old schema, set by old technology. NMR devices did not produce the images—at least not at this point—radiologist were used to interpreting. In fact, one could argue that NMR would never produce those images, as these new devices produce a map of chemical composition of a certain part of the human body, creating information far superior, at least in some respects, to the morphological or shadow images radiologists fully comprehend. However, this inherent distinctiveness of the new devices was not significant to those evaluating them through the lenses of previous institutional schema. Finally, it seems remarkable how intelligent the radiologists leading this committee were. Even when they did not see any significant potential in the new devices, they recommended to the leadership of the ACR that the organization lend its support to the community evaluation, through a conference focused on those new devices sponsored by a key government agency. This seems to indicate that the radiologists were able to imagine that this technology might become relevant in the future, and being at the table of actors assessing that new and "improved" technology would be advantageous for the ACR anyway.

Although the data I collected within the ACR archive did not give me any extra information about the details of the ACR's awareness of the emergence of NMR, I have come to understand that Dr. Alexander R. Margulis was a significant part of the ACR leadership team. In addition to being a member of the ACR, Dr. Margulis was the director of the University of California–San Francisco (UCSF) Department of Radiology. From this position, he had a significant influence on the evolution of the NMR devices. From funding the initial investigations led by Dr.

Kauffman, Dr. Crooks, and Dr. Grover in September of 1975, to buying and helping in the development of the first two devices created by this research team (and commercialized by Diasonics, Inc.) in early 1981 and early 1982, Dr. Margulis had a role to play in the emergence of NMR devices. Unfortunately, I have been unable to find any documentation of Dr. Margulis overtly discussing his experiences with the leadership team between 1975 and 1979. Dr. Margulis' involvement in NMR development and the ACR's response will not finish here, and his role will be highlighted again in other sections of this model. Even so, I can argue that the ACR (and/or its top management team) became aware of the emergence of NMR devices at some point between late 1975 and late 1979.

Sense-giving

Although one would expect to find in the data gathered evidence documenting some kind of internal sense-making process or discussion focused on trying to understand what the emergence of this new technology would mean, my data-gathering effort failed to provide any evidence supporting this activity. This could clearly be a weakness of my archival approach to this investigation, because I was not able to observe or to obtain any documentation proving this internal process. Notwithstanding this potential weakness of my methodological approach or data-gathering effort and according to some scholars, there is another potential explanation for the lack of evidence documenting this internal process of sense-making. Sense-making is an active two-way process of fitting data (the world perceived) into a frame (mental model) and fitting a frame around the data. Neither data nor frame comes first; data evoke frames, and frames select and connect data. When there is no adequate fit, the data may be reconsidered, or an existing frame may be revised (Klein, Moon, & Hoffman, 2006).

This explanation would support the finding of a strong internal sense-giving effort performed by the chairman of the Board of Chancellors (the top executive of the ACR) when arguing within his monthly *Message to the Membership,* subtitled "X-ray Departments or Departments of Medical Imaging," soon after the organization became aware of the emergence of NMR, that:

> **I # 11 (Feb 1980):** From their very inception, radiology departments had, for their rasion d'être, the responsibility of *producing a pictorial representation of the interior of the body* that was useful in the diagnosis and detection of disease. The radiographer "wrote" his picture with x-ray photons. Now the term medical imaging has sprung up and is popularly used to designate the production of images by ultrasound waves, radionuclide and ct scanners as distinguished from conventional roentgenograms. As one who has spent most of his professional life in the production and interpretation of medical images produced by x-rays, *I resent being excluded from the field of medical imaging. Diagnostic radiology is, always has been, and always will be medical imaging*. Medical imaging, although including conventional diagnostic x-ray, is a much more encompassing term and *refers to the production of an image that contains diagnostically useful information, from any portion of the body, regardless of how was produced*. Thus, whether the image is produced by gamma photons, electrons, heat, ultrasound waves, radionuclide, or *Nuclear Magnetic Resonance*, it is still properly *termed medical imaging, and lies within the province of diagnostic radiology.* (emphasis added)

This quote from the top executive of the ACR is quite instructive, and, I would argue, it is at the core of the strategic response of the ACR to the emergence of this new technology. First, it clearly shows the sense-giving effort by the ACR's leadership, through the redefinition of diagnostic radiology, or radiology in general, as a more encompassing field, a professional space defined by the words *medical imaging*, and the linked task of producing and interpreting a pictorial representation of the interior of the body that is useful for the diagnosis of disease. At the core of this abstract reconceptualization of the professional jurisdiction (Abbott, 1988) is the idea that if one is dealing with an image of the human body, then, that person is dealing with radiology. This effective management or *re-crafting of professional space* is constant through the whole process described in this theoretical framework. The second important issue here is the tone the leader used. This statement exudes resentment for being excluded from a field, a domain, that has been his professional life—something, no doubt, central to many professionals who go well beyond the hours spent at work or the income that implies. This also seems to be the common theme permeating the claims and the discourses used by ACR leadership throughout the whole process: this is not something peripheral for them; it is about their life, and it is infused with value (Selznick, 1949, 1957 [1984]). Finally, this re-crafting allows the ACR and radiology in general to sustain a central tenet of the organizational response to the emergence of NMR devices: they belong to the province of radiology.

Sense-making (Participation in Community Negotiation of Meaning)

As noted in the previous subsection, although no evidence could be found of sense-making within ACR staff or leaders, multiple indicators were found supporting the participation of the ACR in community-wide initial evaluation and negotiation of meaning for the new devices. In fact, the first community-wide formal assessment of this technology, a three-day symposium held in Colorado Springs, CO, was organized and hosted by the ACR, but the funding was shared with the FDA, the Bureau of Radiological Health, and the National Cancer Institute. The same committee that officially brought word of the emergence of this new technology—the Committee on Emergent Imaging Modalities of the Commission on Equipment—was the acting host of this symposium. The name of the symposium was “Current Developments in Medical Imaging—An Evaluation (NMR, Ultrasound, Transmission CT, Emission CT, Electronic Processing and Recording)” (ACR, 1980). Discussing the details of the symposium goes beyond the scope of this investigation, but, when considering the discussions centered on NMR, it seems important to note that representatives of key community organizations actively participated in this meeting. Some of these key actors were Dr. Meaney, Dr. Evens, and Dr. Seaman from the ACR, representatives of Philips Medical Systems and General Electric, representatives from different NMR research teams (Dr. Bottomley, Mr. Crook, Dr. Hinshaw, and Dr. Moseley), staff from different government agencies (the Bureau of Radiological Health, the National Cancer Institute), and some key academics. The chairman commented in the *ACR Bulletin* published soon after:

> **I # 36 (Aug 1980):** The session clearly established the involvement of radiologists and their colleagues in the development of these new modalities[…] While we cannot predict which one of these will gain widest acceptance, all five have advanced far enough to justify the serious attention of the college and the entire radiologic community […] *the acceptance of radiologists and their willingness to make purchasing decisions represented an informal but effective assessment process without organization or clearance of federal agencies or professional societies*. Dr. Moseley emphasized *the ultimate test of an imaging system is the ability of a trained observer to gain more and better information that was possible from competitive technique*s. (Emphasis added)

Three issues emerge from this piece of evidence and the community-wide sense-making effort that this incident indicates. First, it seems important to note who is at the table when defining the utility or value of the new technology. In addition to which research teams or manufacturers participated or which government agencies led this community-wide sense-making effort, it is especially important to highlight the role of the ACR, and who represented the organization. The ACR not only participated in this community-wide sense-making effort, they also hosted the conference, set the agenda, and even published the proceedings. These activities portray an actor who holds significant influence in the assessment of this new technology, even when a priori radiologists did not have specific expertise in terms of magnetic fields and even less formal training on the physiology/chemistry of the human body (the contribution made by the readings of the new technology). A second important issue to consider is the philosophical position the ACR has in terms of regulation and the government and the role they conceive for radiologists. The ACR and many radiologists see government as intrusive and ineffective—an entity that has hindered their actions and ideas. Furthermore, they see radiologists as having key control on the evolution of the new technology through “their purchasing decisions.” This would be, again, a key tactic radiologists used throughout this process. Finally, it is interesting to consider how the ACR sees the ultimate test for assessing whether a new technology is worthwhile. This test considers whether a trained observer—one could replace the words *trained observer* here for the word *radiologist*—gained more and better information than was possible from competitive techniques. Although, this assessment technique is not inappropriate, necessarily, key actors could not help but wonder what would happen with technologies that brought a completely new set of data that could open unimagined avenues to patients but remained impossible to be understood by trained observers at that point. Was the technology or the trained observers worthless?

Now that the first stage in the process is summarized, is time to move to the second stage. How can we know that a qualitatively different stage has emerged? In addition to seeing how the actions in the next stage are qualitatively different, I would like to note a concomitant change in the main stimulus of action of the ACR. From late 1980 to mid-1981, NMR devices had improved significantly in terms of quality of images, but also in the concrete application to clinical medicine. Perhaps more important, FONAR had presented at the ARRS meeting its QED 80 model and had even sold one of this units to a private radiological clinic in Cleveland.

> **March 1981, Diagnostic Imaging**: Clinical trials are being performed with the first NMR system to be installed in a clinical setting. According to Dr. Ross, of Ross, Lie, Thompson & Associates, the private radiology practice in Cleveland that acquired an NMR scanner late last year, the trials will establish baseline normal and abnormal NMR images and values for anatomic structures in the human body. This practice operates a 3M$ diagnostic center that contains a full complement of fluorography, radiographic and ultrasonic equipment. In 1975, the group installed the first head and whole body CT scanner in a private practice office […] According to Ross, he views NMR as a *complementary modality that should be used in conjunction with CT, ultrasound, nuclear medicine and other radiographic techniques. By providing information on tissue chemistry, NMR adds another facet to the diagnostic process*, he said. Studies from the various modalities in the Cleveland practice will be compared to define NMR's *place in radiology*. […] He indicated in an interview before the symposium that, as more information is gathered, the role NMR will play in diagnosing disease processes will become more firmly established. Initial response to the NMR scanner has been good from both patients and referring physician, according to Ross […] The

> installation has already been visited by physicians from throughout the U.S., Japan, Sweden, China & Belgium. (emphasis added)

This meant that NMR was no longer a toy of certain researchers, but rather, something that radiology, and therefore the ACR, would have to respond to. It seems important to note from this article published in *Diagnostic Imaging* that the first NMR was purchased by a private clinic, but perhaps more importantly by a radiological clinic, clearly indicating the evaluation of the technology as a complementary tool within the broad set of apparatus managed by radiologic professionals. It also seems necessary to note that the owner of the clinic clearly understood the implication of the use of NMR: the evaluation of tissue chemistry (physiology).

Another way of indicating how a new type of response was necessary from the ACR is by assessing the reaction of the technological community to the presentation of the QED 80 at American Roentgen Ray Society:

> **May 1981 Diagnostic Imaging (Editorial Note by Paul Brown):** Since 1895, when Roentgen produced the first medical radiographic images, *the radiologists' primary role has been to distinguish disease by differentiating normal and abnormal morphology*. But the rapid infusion of high-technology equipment in the past few years is changing radiology so much that it's almost not the same science […] Undated reports on digital radiography and *NMR commanded the radiologists' attention at the March 22 annual meeting of the American Roentgen Ray Society* in San Francisco […] *NMR is also said to provide functional information by evaluating chemical properties*. The technique has not reached the level of development that digital radiography has, and as yet *its clinical possibilities are untried*. The role NMR will play in radiology is not quite as well defined. The technique intrigued radiologists who crowded [the presentations by] who is who in NMR research [from G. N. Holland (Nottingham/GEC), J. Gore (Hammersmith Hospital), UCSF, W. Edelstein (Aberdeen/GE), P. Lauterbur colleagues, R Nunnally (U of Texas), West German researchers (Siemens) and HE Simon (Technicare)[…] No researcher was willing to speculate on NMR's clinical potential "*We are not really in a position to predict clinical effectiveness"*, Holland said. For the most part *the researchers are physicists who have been schooled in electrical engineering. "We can't compare NMR with other radiologic modalities because we are not familiar with them ... We can only make NMR work and tell you what it does. It's up to radiologists to decide how useful it is"* […] Researchers at the gathering were in agreement that phosphorous imaging will probably be limited to biophysical research applications. *The devices that the radiologists will use will image hydrogen, which is much more plentiful in the body and gives a stronger signal-to-noise ratio than any other element.* (emphasis added)

Multiple issues can be noted from this editorial report. First, one notices that radiology is described as science and, more importantly, that the editor of *DI* spelled out the key implication of the emergence of NMR devices, considering it as a “seismic” movement from morphology, where the historical expertise of radiologist resides, to functional information, chemistry and physiology, a knowledge base barely understood by radiologists. Second, one observes that the creators of these new devices were mainly engineers and physicists who were unable to contextualize the function of the new devices for radiologists attending the conference. Joyce has argued that this movement toward radiology was a critical survival shift by key NMR research groups trying to gain legitimacy, new funds, and potential clients (Joyce, 2001). This is particularly relevant if one considers that the lack of a preferred meaning or use offered by the creators of these devices left an open space to be occupied by radiology’s own preferred use or meaning. It is also imperative to contextualize this fact by remembering the argument, previously discussed by Michael Goldsmith, a key member of Damadian’s post-graduate team, when noting that pathology reacted negatively to the emergence of NMR. Finally, it is essential to stress how radiologists, according to the *DI*’s editor, were likely to prefer hydrogen, or proton, NMR devices, given their better signal-to-noise ratio, and therefore, their better image quality. In other words, hydrogen-focused NMR devices are more capable to produce images the typical way radiologists conceptualize the output of their machines. This would be critical in the future development of the technology if radiologists were given input, as other type of NMR devices, such as those focused on detecting phosphorus or other clinically useful chemical markers of disease, were displaced.

Beyond these specific details, this concrete emergence of NMR devices as clinical machines likely pushed the ACR to move beyond mere sense-making/sense-giving activities and to enact additional actions. Those supplementary actions are described in the second stage of my theoretical framework.

Stage 2: Goal Setting

The actions that the ACR committed itself to in this stage cover a span of a few months, from September of 1981 to January of 1982. The title of this quite consequential stage is “goal setting” because these actions match with the imagery of a “purposeful and adaptive entity […constructing] an envisioned end state, tak[ing] action to reach it” (Poole et al., 2000: 61). The ACR created—in September of 1981 after the 1981 Summit Meeting—a large boundary-spanning internal structure denominated Commission on Nuclear Magnetic Resonance. This group had specific goals and even internal structures with specific subtasks and objectives. These actions were summarized in the first issue of the 1982 *ACR Bulletin*. Before going into the details on the commission, leaders, and specific goals by substructure, it seems essential to stress how the technology and this commission were presented to the bulk of the ACR membership. Figure 24 shows images of the cover page and page 3 of that particular issue.

These images are an essential part of my argument for several reasons. First, the image on the cover shows a low-quality NMR image of a human head, followed by the phrase, “What is it?” One could infer from it that most ACR members—and therefore, most radiologists—knew little if anything about NMR devices and their outputs. The following image corresponds to the beginning of the cover’s article on page 3, which answers the question asked on the cover by saying, “It’s NMR!” This is further evidence that the ACR’s leadership knew that most of its members would not know the answer to the question, and they tried to stress the importance of the answer at the beginning of the article. Taken together, this seems to present further evidence of the low level of awareness most radiologists had about the development of NMR devices over the previous decade.

It is vital to show how the new technology was presented to ACR's members (what I would argue is an internal sense-giving activity):

> **I # 86 (Jan 1982):** There is a new image in your future, and now is the time to see it clearly. It's called NMR, or nuclear magnetic resonance, and *its potential is astounding*. To enable radiologists to quickly grasp the use and importance of NMR, the ACR has established a Commission on Nuclear Magnetic Resonance, which is being *chaired by Thomas F. Meaney of the Cleveland Clinic.* […] Further, the Commission will *act as a resource to health care providers and to policymakers as this modality moves into the clinical arena. Hopefully, the commission will be able to avert many of the problems, which arose during the introduction, and clinical application of ct scanning*. An initial objective of the commission will be to *evaluate present and future research and all clinical work to deter various clinical applications*. Data collected within the next two years or more will be compared with that from other imaging modalities. Also, *a prospectus of the basic technology of NMR is being developed and will be available to members by mid to late 1982.* […] Dr. Meaney urges members to carefully follow the preliminary trials conducted with NMR and to attend one or more of the many seminars that will be offered in 1982. *Complete comprehension of NMR will permit the radiologist to act quickly to integrate it into the radiology department* when the technology reaches the stage of clinical applicability. "While t*he physics of NMR will be strange to many radiologists, the image analyzes will be easy for those skilled in interpreting ct and ultrasound studies"* […] Dr. Meaney said he, and many other physicians believe the new technology *will replace ct for neurological applications and probably for many body examinations*. Domestically, clinical studies are under way at UCSF, Massachusetts General Hospital (resistive magnet for head examinations). Clinical work will be started soon at the *Cleveland Clinic*, the U. Hospitals in Cleveland, and the U. of Pennsylvania. Dr. Meaney noted that some of the non-patient research has been done by *non-radiologists, which may be a portent for the future use of this new imaging modality. It behooves radiologists to become NMR experts if they want to be at the forefront of its development and implementation*. (emphases added)

This initial presentation of the technology to ACR's members contains several key ideas to understand what the ACR planned to do and what they were asking from their members. First, it shows the ACR's leadership team as one that had no doubts in actively dealing with a new technology that was seen as having astounding potential. Second, it stresses that the new commission would try to interact with members, health-care providers, and other community members to avoid some of the problems generated by the emergence of the last innovative technology, the CT scan (a key use of previous experience by the ACR). Third, it promised to its members to have ready in the upcoming months a printed resource so they could learn more about this new technology. However, this service also comes with a two-step call for action: comprehend the new technology quickly so you can integrate it quickly "*into radiology departments,*" and later remind members that "it behooves" each of them "to become a NMR expert" to stay at the forefront in the "development and implementation." These calls for individual action were central to the ACR's actions, because they realized that, although they would act in behalf of radiology; individual action (by purchasing and locating these devices within radiological departments) would also influence how the new technology would affect the profession. In addition, this call gave ACR's members a mandate not only to be "mere users" or "interpreters" of the technology, but they had to go beyond that and actively participate in the "development" of the technology—in other words, become scientists too.

Finally, the chairman of the new commission also hinted that the commission would proactively participate in this evolutionary process of the technology by "*deterring*" various clinical applications (more on this later). ACR's leadership team did not simply wait for the actions of its members, and they clearly informed their readership of what they planned to do to make sure that NMR would become part of radiology by detailing the objectives of each subunit (committee):

- (1) **Committee on Investigational Resources** : Identify and monitor potential sources for support of experimental and clinical investigations (Chairman James E. Youker)
- (2) **Committee on NMR Imaging Technology & Equipment**: Identify the various NMR imaging technologies in use and in development, *develop an uniform equipment specification terminology and attempt to persuade manufacturers to use standard terminology or otherwise define meaning of their specifications*, translate the perceived or known advantages and disadvantages of various technologies and equipment into useable info for the radiological community (Chairman Alexander Margulis)
- (3) **Committee on Clinical Applications**: Monitor clinical investigations on NMR imaging and *in-vitro spectroscopy in the U.S. and abroad*, identify the potential

applications of NMR in various organ systems, develop methodologies for a dialog between clinical investigators in the field, communicate finding on a regular basis to the C. *on Government Affairs and the C. on Education and Training*. (Chairman Juan Taveras)

- (4) **<u>Committee on Biological Effects</u>**: Provide information to radiologic, industrial and other publics regarding present knowledge on biological effects of NMR, monitor new information or evidence in the field ad update, *cooperate with federal and state agencies in the development of policies and standards for human subjects, and develop policy standards on safety and hazards of clinical NMR.* (Chairman Thomas Budinger)

- (5) **<u>Committee on Government Affairs:</u>** Monitor legislative and regulatory activity in the field of NMR, *develop proactive plans to influence the government on legislative and regulatory*, develop policy statements on the diffusion of NMR units for presentation to the Board of Chancellors & Council, *develop policy statements to educate insurance companies and other fiscal intermediaries regarding reimbursement for clinical NMR, stimulate government grants for NMR research.* (Chairman A. Everette James, Jr.)
- (6) **<u>Committee on Education & Training</u>**: Provide *basic information to the radiologic community regarding fundamentals of NMR imaging and in-vivo spectroscopy, clinical potential of NMR, equipment & technology*, *Sponsor seminars on this subject, including selection of faculty and organize the activity for ACR members*, Sponsor forums for *advanced discussion of researchers in the field and disseminate proceedings to appropriate parties, e.g., government users and industrial community*, identify and publish available postgraduate visiting fellowship opportunities for radiologists, develop methods to document postgraduate activities of radiologists in NMR (Chairman Richard Greenspan)
- (7) **<u>Committee on NMR molecular analysis</u>**: Identify potential clinical application of NMR in-vivo spectroscopy, identify present and potential clinical applications of in-vitro spectroscopy (beyond the usual and standard chemical analytical techniques), communicate with the C. on Education in developing methodologies to inform the radiologic community on NMR clinical analytical methods, *in liaison with c. on government affairs, attempt to unify NMR imaging, in-vivo & in-vitro spectroscopy under the total umbrella of clinical NMR.* (emphases added)

The ACR leadership presented a clear and comprehensive plan to assure their members that they were taking seriously the emergence and threat of NMR devices. Perhaps part of their final success resided in this type of comprehensive and strategic action plan. A few issues can be stressed from this action plan. First, it is critical to single out key figures within this commission and its committees. I would like to highlight the involvement of Dr. Meaney, the chairman of the whole commission, and committee chairmen Dr. Margulis and Dr. James. Dr. Meaney was a critical subject in this whole process, because, not only was he a key figure within the ACR's power structure as speaker of the council, but also he represented the ACR in the first community-wide symposium about NMR. Perhaps more importantly, he also played a larger role in two other aspects of the ACR's response to NMR and in the development of NMR itself. Dr. Margulis, as previously mentioned, was perhaps the first member of the ACR leadership team to become aware of NMR devices, and, more significantly, he was a key funding agent and contributor to the UCSF's NMR program (commercialized later by Diasonics, Inc). This shows how a creator of the technology would also participate in its evolution by simultaneously being part of one of the companies developing the technology and part of the ACR's efforts to steer the technology development to fit radiology's preferences. Dr. Margulis and Dr. Meaney "walked the talk" the ACR gave its members when actively participating in the acquisition, research development, and clinical use of the NMR devices through their positions in the radiological departments of the University of California–San Francisco and Cleveland Clinic respectively. Second, and no less essential than who led the plan of action, is the content of the plan itself. As noted in specific objectives of different committees, the ACR planned to (1) steer a uniform equipment specification terminology and persuade manufacturers to use standard terminology or otherwise define meaning of their specifications; (2) steer the development of policies and standards for human subjects, safety, and clinical applications through cooperation with federal and state agencies; (3) develop proactive plans to influence the government on legislative, regulatory, and policy statements to educate insurance companies and other fiscal intermediaries regarding reimbursement for clinical NMR; (4) stimulate government grants for NMR research; (5) disseminate proceedings internally and externally (e.g., government users and the industrial community); (6) attempt to unify NMR imaging, in-vivo and in-vitro spectroscopy under the total umbrella of clinical NMR.

Each of these actions were implemented at different points in time, and with different degrees of success. These actions compose the following stages in the theoretical framework described below.

Stage 3: Normalization by Steering Understanding (Fitting NMR into Old Cognitive Structures)

This stage involves the first set of actions (encompassing approximately 20 incidents from the incident sequence file) enacted by the ACR from early 1982 to late 1983. In terms of the concomitant evolution of NMR devices, this was a period in which NMR devices were still being sold mostly to big university hospitals and the cumulative number of units in the United States was less than 20.

One could argue that during this period clinical studies verifying the safety and effectiveness of these machines consumed most of the time of the creators of these devices. Furthermore, other factors contributed to the increasing interest in NMR devices. One of these factors was the publication of an 854-page study, "Federal Research on the Biological & Health Effects on Ionizing Radiation" was carried out by the National Academy of Sciences at the request of the National Institutes of Health, reviewing and evaluating the effects of ionizing radiation. The committee's two-year research effort identified about 900 research projects supported by 15 federal agencies. The committee in charge of this report argued that the diagnostic use of radiation has unmistakable medical benefits and called for increased support of research to ensure that the best and most cost-effective technologies for dose reduction and improved diagnoses were available to the public. This was, arguably, a big boost for those doing research with NMR devices, as they could refer to this report when justifying how NMR technology (based on apparently harmless magnetism) may benefit the public.

In January of 1982, the Bureau of Radiological Health published key policies that facilitated even more the research on these new technologies by reducing their liability risks, and therefore generating a larger number of investigations focused on NMR devices even beyond universities:

> **ACR Bulletin (Jan 1982)**: Three guidelines for determining when a Nuclear Magnetic Resonance System might pose a significant risk to a patient, thus requiring an Investigational Device Exemption (IDE) were issue in U.S. Bureau of Radiological Health (BRH). Sponsors of clinical investigations, researchers and institutional review boards are to use the document in deciding whether to apply to the FDA for an IDE. Under the guidelines, "whole or partial body exposures to static magnetic fields of 2 Tesla, time varying magnetic fields of 3 Tesla per second or radiofrequency electromagnetic fields resulting in a specific absorption rate exceeding 0.4 W per kilogram over the entire body or 2 W per kilogram over any one gram of tissue do not present an unacceptable risk" said the BRH. The Bureau said the document should not be used beyond determining if a request for an exemption is necessary. While admitting the guidelines are *"somewhat arbitrary",* BRH said, "They are not general safety recommendations for workers of the general public." The guidelines would be revised in the future on the basis of new findings. According to the guidelines a "significant risk" contains the "potential" for "serious risk" to patient's health, safety or welfare, but does not mean, said the bureau, that a device is too hazardous for clinical studies. (emphasis added)

From this official note, one can see that governmental offices, as with many other community members, did not have a complete grasp of the limits or the potential short- and long-term consequences of the use of these devices, but they had to provide some kind of guidelines given their potential benefits. This lack of clarity on the meaning and uses of the devices presented an opportunity for the ACR—an opportunity aligned to its plan to respond to the emergence of these devices. This first set of actions enacted by the ACR can be described as seeking to steer the community-wide efforts to define the meaning of this technology and to give particular meaning to key aspects of the technology itself. These actions can be grouped into two types according to the actors the ACR was trying to influence: internal and external.

Internal Steering (Normalization by Sense-giving and Members' Training)

Although these types of actions represent the smaller part of the set of events associated to this stage, they are as important to other actions taken by the ACR. In particular, those actions linked to steering comprehension of the ACR's own members not only served for ACR's leadership to offer a certain preferred meaning to its members, but also was functional for those members when encountering jurisdictional arguments in their daily activities or particular organizations as a way of legitimating their claims over the new technologies. A typical example of this type of actions is:

> **I # 110: Memo to the Membership (by Chairman of the Board, Dr. John Harris):** I recently received a letter from F. Behike, chairman of the Radiology Imaging Department of the Sierra Medical Center in El Paso, *decrying the use of such terms as* "*Department of Medical Imaging" or "Medical Imaging Center"*. This type of designation occurs with increasing frequency in the lay press and is not entirely unheard of in scientific publications, as well. Dr. Behike advocates, and *I certainly support his notion, the use of terminology, which includes a reference to radiology*, such as "*Department of Radiologic Medical Imaging", "The Radiological Medical Imaging Center", or "Medical Imaging Radiology Center or Department"*. The addition of digital angiography and *NMR* to ultrasound, all of which are, or can be, performed by non-radiologists, makes it incumbent upon the radiologic community *to promote and advocate the concept that these procedures are within the scope of radiology, and not weaken that position by the use of such terms as "medical imaging"*. (emphasis added)

Another type of action linked to steering the comprehension of the new technology is linked more with actual training and functional learning of the new devices. A typical example follows:

> **I # 97 (ACR Bulletin–Feb 1982):** New imaging technologies and their applications emerge and change with a swiftness any radiologists could call bedazzling. To help you cope with the dilemmas created by the proliferation of new technologies, the ACR is arranging for another seminar on Department Planning and More Postgraduate Courses. An update for the 1981 symposium on Diagnostic Radiology: How to plan for the 1980s will be held, October 15-17 in Chicago. At the fall session, innovative speakers will provide comprehensive analysis of the ramifications of digital subtraction angiography, *NMR*, nuclear radiology, CT,

> ultrasound, and conventional x-ray systems. J. Krohmer, Chairman of the Committee on User Education, will focus on *the acquisition of new equipment and how it can be integrated into radiology departments* […] *the role of CT will be compared with other imaging modalities, including conventional radiology, angiography, ultrasound, radionuclide imaging and NMR*. […] one of the headliners will be a seminar coined: New Imaging Modalities: What Do They See? Replacements or Supplements? Participants will hear in depth reports on current and developing digital systems, the *exciting prospects for NMR*, the use of computers and what to expect from health planners and regulators. (emphasis added)

However, the ACR not only tried to influence the comprehension of its own members to the new technology, but also it actively steered the comprehension of many other members of the technological community, which can be seen in the discussion that follows.

External Steering (Normalization by Re-crafting of Community Schemas/Categories)

These types of actions were the most common in terms of frequency during this stage. It seems that they explicitly sought to "normalize"(May & Finch, 2009), or, in other words, tried to make the NMR devices fit previous schemas or categories that were chosen by the ACR. Typical examples of this type of action follow:

> **I # 152 (ACR Bulletin–Jun 1983):**A glossary of 200 conventional NMR related terms is available from the ACR […] Thomas F. Meaney, Chairman of the ACR Commission on Nuclear Magnetic Resonance, said *it is hoped the definitions and conventions will be used as standards in writing scientific articles*. […] The glossary has been *endorsed by the Nuclear Magnetic Resonance Section of NEMA*[…] was produced by the NMR Sub-Committee on Nomenclature and Phantom Development, chaired by Leon Axel, PhD, MD, under the Committee on NMR Imaging Technology and Equipment, chaired by Alexander R. Margulis, MD. (emphasis added)
>
> **I # 169 (ACR Bulletin–Nov/Dec 1983):**To alleviate patients' concern that the word "nuclear" might suggest radioactivity, the ACR commission on Nuclear Magnetic Resonance has recommended adoption of the term "Magnetic Resonance". In a unanimous decision, the commission decided that adoption of the term *would also provide sufficiently nonspecific terminology to include the future possibility of electron spin resonance*, which might not be covered by terminology confined to atomic nuclei. (emphasis added)

> **I # 169 (Radiology–Nov/Dec 1983):** Thomas F. Meaney noted that "almost as soon as NMR systems became available, debate centered on the name 'Nuclear' […] many considered that this word might suggest that radioactivity is associated with the procedure in the mind of the general public, and, more specifically, patients undergoing examination. A new society composed of respective investigators in NMR was formed […] and choose the name 'Society of Magnetic Resonance in Medicine', omitting the word nuclear. Some scientists believe the use of the name NMR is restrictive, since […] future clinical possibilities might not be covered by terminology confined to atomic nuclei. A number of descriptive terms have been suggested as alternatives.
> These include, *Magnetic Resonance Imaging (MRI)*, Magnetic Resonance Spectroscopy (MRS), Magnetic Resonance CT and Medical Magnetic Resonance. Advocates of these terms believe they are more descriptive, more accurate and would obviate the public's concern about the word 'nuclear'. While some of these descriptors are appealing because of specificity, e.g. MRI, MRS, they might tend to provide impetus, through terminology, for division of the field into imaging and spectroscopy […] *Some relate to possible turf issues by suggesting that the use of the term 'nuclear' would imply inclusion of this technology into the field of Nuclear Medicine or Nuclear Radiology. Present trends in the acquisition of NMR systems indicate, with few exceptions, that NMR systems are being placed in departments of radiology. Expertise, rather than a name will ultimately dictate issues related to 'turf'*. At a recent meeting, the ACR's Commission was unanimous in recommending the adoption of the term *'Magnetic Resonance'. Such terminology is sufficiently nonspecific to include [other future technologies] but appropriate in unifying both imaging and spectroscopy*. The ACR commission has begun the process of publicizing its decision by changing its own name, and hopes that use of 'MAGNETIC RESONANCE' by investigators, educators, contributors to scientific literature, editors of scientific publications, and by the industry will help to standardized the terminology for medical applications and avoid confusion at most levels of communication." (emphasis added)

All these actions seeking to influence the early comprehension of the new technologies were quite successful, although the ACR actions did not always obtain exactly what it was explicitly searching for. Evidence from the industry journal *Diagnostic Image* indicate that they were able, for instance, to impose their glossary as the standard in their field, and they were even capable of changing the name of the technology, eliminating the problematic word *nuclear*. The new name by which these devices were called was MRI, magnetic resonance imaging, a name that was not exactly what the ACR was looking for, but a good approximation that still allowed them to strengthen their direct claim over the new devices, because they were, after all, "imaging" devices. However, these initial tactics and actions would not have been as effective without further battles fought in other domains that emerged because of the continuing evolution of these devices and those practicing medicine with them. These battles are described in the next stage of this framework.

Stage 4: Normalization by Steering Policy & Practice (Fitting NMR into Old Policy & Practice Structures)

As noted in the review of the evolution of the NMR devices, from late 1983 the dynamics in the technological community changed significantly. The triggering event for the emergence of these new dynamics was the decision of the Food and Drug Administration in mid-1983 to change the status of some of these devices from investigational devices to being available for sale with a significant reduction of regulation and controls, what was known as moving to Class III, or pre-market approval. In fact, this long process took a numerous set of decisions by the FDA from mid-1983 to late 1986 for each different company applying for each specific device they had created and intended to commercialize. However, regardless of when any specific company obtained the status change for any specific device, the initial approval of a few devices reduced significantly the uncertainty of final success. This caused many potential buyers to rush to secure the new types of devices that might give them a competitive advantage on attracting the brightest physicians and obtaining a new service to offer to their patients as well as a potentially substantial new source of income.

Given this new expanded set of “users” and even producers of these devices, the challenge of the ACR to control this technology became even more acute. Perhaps because of the magnitude of the challenge, the ACR responded with a wider set of actions, seeking to steer these developments by normalizing the new devices within older policy and practices. From the evidence gathered during this period, from late 1983 to late 1988, one notices a substantive number of events explicitly showing how the ACR influenced concomitantly policy and practice. I describe each of them below.

Policy Steering (Fitting New Devices into Older Policy Structures)

At this point, the ACR was not new to the concept of actively trying to steer policy for preserving radiologists' interests. In July of 1980, Chairman Seaman had argued:

> **I# 26 (Jul 1980):** There is no doubt in my mind that more & more of the ACR's effort, time and money will be directed toward the Washington scene. He then notes that instead of responding to new policies, the *most effective way to influence the regulatory process is by participating in the planning process. This is best accomplished by cultivating relationships with key congressional and senate staff* […] We are fortunate in having a competent Washington staff. In order to *increase our input into the legislative process, serious consideration will be given to enlarging this important sphere of our activity*. (emphasis added)

Similarly, the next chairman, John Harris, in February of 1981, stated:

> **I# 48 (Feb 1981):** Let me remind you a few things done, not by the college, but by members of the ACR staff, […] which do affect our lives as radiologists on a daily basis […] Our right to negotiate independent [separate] billing for our professional fees in a hospital setting, guaranteed under Medicare and Medicaid legislation, *didn't just happen* […] "I have described only a few specific examples in brief detail without mentioning the *pieces of legislation or regulation which would affect us adversely if they were not modified or rejected as result of testimony or college members or staff. We all benefit from the constant monitoring of the Federal Register, legislative hearings, preparations of scientific position statements, and the untold hours of negotiation with HCFA, BRH and other regulatory agencies to prevent further incursions or restrictions on our ability to deliver impeccable care*. (emphasis added)

The ACR took advantage of this previous experience, reputation, and contacts at multiple levels within the old institutional structure of the technological community when seeking to steer policy focused on the new devices. Specific evidence accumulated in the sequence file illustrates concrete actions steering NMR policies within the FDA, a large set of state governments, the American Hospital Association, and even newer scientific evaluations to be used as new evidence to regulate NMR devices. The most common strategy used was the insertion of key figures in expert advisory bodies producing policy recommendation focused on NMR devices, usually those with more experience with the devices—Dr. Meaney or Dr. Margulis among others. Four examples exemplify these types of actions:

> **I# 144 (April 1983):**Manufacturers of NMR imaging equipment were *encouraged by the Advisory Radiologic Devices Panel of the National Center for Devices and Radiological Health to petition formally for a change in the classification of NMR equipment. Leslie L. Alexander, Chairman of the panel*, told industry representatives at a day-long public meeting of the panel in early December that his group would act promptly on a request for a change in classification of NMR imaging equipment from a class III status (requiring premarket approval) to either class II (calling for applicable standards) or class I (mandating general controls). NEMA had requested the meeting with the panel to determine its interest in a petition for change of the classification. Without committing the panel, Dr. Alexander, *who also heads the ACR's commission on public health*, said he and his colleagues would welcome a petition for re-classification and promised its speedy consideration. Both Dr. Alexander and officials from the center emphasized that any review would focus on the medical effectiveness of NMR, based upon scientific evidence available to the public and the government. (emphasis added)
>
> **I# 178 (March 1984):** Thomas F. Meaney (Chairman of the Commission on Magnetic Resonance) cautions that *widespread use of MR is unlikely until Medicare and the private carriers begin reimbursement for MR examinations*. The ability to change is a whole different matter from getting reimbursed" says Dr. Meany […] "FDA approval should trigger the *federal government to evaluate the suitability of MR procedures for reimbursement under Medicare",* Otha Linton says (Director of ACR's governmental relations). The Public Health Service Office of Health Technology Assessment will be making a study and recommendation to the HCFA about whether Medicare should reimburse for MR examinations or not. "*The College will be assisting them in making that evaluation"* says Mr. Linton. A committee is now being constituted by the Office of Health Technology Assessment and should reach its conclusion in six months to a year. The college hopes to nominate a member of that committee**.** *Medicare reimbursement would clear the way for private insurers to adopt formal reimbursement programs for MR examinations. "The process has begun"*, says Mr. Linton. (emphasis added)
>
> **I# 220 (Feb 1985):** 3 members of the ACR have been appointed to a FDA Committee on Imaging Technology. Thomas F. Meaney, member of ACR's Board of Chancellors […], Francis Rusicka, chief , Diagnostic Imaging Research Branch, National Cancer Institute (NCI) have been appointed to the *Technology Coordinating Committee* (TCC) *Subcommittee On Imaging*. Gordon Johnson, deputy director, Office of Health Affairs at the Center for Devices and Radiological Health, was appointed Subcommittee chairman. The work of the new subcommittee will be used by the Public Health Service Office of Technology Assessment to *conduct reviews of medical technologies*. The reviews constitute the basis for Public Health Service recommendations to the Health Care Financing Administration for Medicare Reimbursement. The TCC specifically addresses issues of *safety and efficacy for new & existing technologies*. The subcommittee on imaging was established "to ensure that imaging technologies are examined in a systematized manner, which may assist in a determination of specific areas of efficacy and their proper role in health service delivery" The subcommittee was not established to make coverage and reimbursement decisions or to enter into development of algorithms for patient care. One of the first goals of the Subcommittee is *to develop & examine issues pertaining to magnetic resonance imaging in the context of medical imaging in general*. (emphasis added)

> **I# 185 (Jun 1984):** The Blue Cross & Blue Shield Association announced guidelines on imaging on June, intended to discourage medically unnecessary and ineffective diagnostic imaging procedures[…] *The ACR was involved with the development of the guidelines at every stage of their preparation over the past two and half years*. G. Dodd, Chairman of ACR's Board of Chancellors, *represented radiology at the Washington press conference* where the guidelines were announced. (emphasis added)

All of this evidence seems to provide support for the type of policy-steering actions that dominated the first period of this new stage. However, the ACR not only tried to steer policy, but they also ended up influencing the medical use these new types of devices by changing the outputs of these devices and fitting them within the older coding system dominated by radiologists. A description of this type of actions follows.

Practice Steering (Fitting New Devices into Older Practice Structures—New Output as Old Images)

If one remembers that influencing the way NMR devices were developed was a critical goal of the ACR, assessing this type of action by the ACR becomes central for this model. In fact, the Commission on NMR had as an explicit objective that of "*deterring various clinical applications*" by unifying NMR imaging and spectroscopy under the total umbrella of clinical NMR. Unfortunately, the data I collected at the ACR archive did not reveal concrete actions conducted by the ACR. However, I did find data describing the influence of radiologists on the development of NMR devices outside the ACR archive.

Indeed, Kelly Joyce (2001, 2008) collected concrete evidence from her interviews with key researchers and developers of NMR devices, noting how the outputs of these machines were changed explicitly toward the preferences of radiologists. She notes that in her conversations with Mallard, Damadian, and Crooks, all of them noted that originally their machines produced as an output both "an array of numbers and anatomical image […] usually printed in multiple colors" (Joyce, 2001: 43/44). They justified these choices by stating that they strongly believed at that point that the "actual knowledge of T_1 and T_2 , rather than translating it into pixel brightness would give additional" (Joyce, 2001: 44) information about a person's anatomy and health. However, these three informants agreed on explaining that as NMR devices were tested and used by radiologists, and they actively shaped the output, preferring the known shades of gray in which their knowledge base rested. Thus, Mallard told Dr. Joyce, "The radiologists couldn't abide by colors. They were used to gray scale on their x-rays and they wanted gray scale. So we put gray scale. Everybody were used to gray scale and color was dropped" (Joyce, 2001: 48). He also confirmed to Dr. Joyce that although the original machines could actually publish numbers and colored images, and they interpreted both indistinctly, "Radiologists don't think in that way… Radiologists just weren't interested in the numbers. They never have been" (Joyce, 2001: 49). Mr. Crooks, a key member of the UCSF team, described the same phenomenon to Dr. Joyce in the following way: "We were in radiology department. The docs make their living looking at images" (Joyce, 2001: 49). It is known, however, that at least within the UCSF team, the technology was shaped while being used to the practice of medicine by the action of one of the members of the ACR's Commission on NMR, Dr. Margulis.

Beyond this influence of radiology—and perhaps of the ACR—in changing certain aspects of the outputs of NMR devices, the ACR was actively involved in other types of normalization of the technology. The description of those actions follows.

Practice Steering (Fitting New Devices into Older Practice Structures—Medical Coding/Jurisdiction)

In addition to being successful for the most part in steering certain policies linked to NMR devices, the ACR was actively involved in influencing the new practice of medicine relying on these devices. In so doing, they tried to fit NMR exams into the older institutional structure of medicine and thus normalize NMR devices as another typical exam performed by diagnostic imaging within radiological departments. The events showed below are exemplary of these types of actions:

> **I# 257 (Mar 1986):** Proposed codes for magnetic resonance systems which would be incorporated in the current *Third Volume of the International Classification of Diseases, Ninth Revision, Clinical Modification* have been *recommended by the ACR* to a special committee of the Department of Health and Human Services (HHS). *The following MR codes have been suggested by the ACR Commission of Magnetic Resonance to the government's ICD-9-CM coordination & maintenance committee*: 88.9 Magnetic Resonance; 88.90 Magnetic Resonance of Brain & Brain Stem; [...] Implementation of the new MR codes is expected Oct 1, 1986. However, prior to meeting this effective date, the proposal must move through various stages of government approval. *All such code changes that affect reimbursement must be approved by the national center for health statistics and the HCFA*. […] In addition, most proposed changes affecting HCFA's diagnosis-related group classifications under Prospective Payment must be issued for public comment in the Federal Register. HCFA expects to publish the proposed rule by April 1, 1986 [*...Approved by Oct 1986*]. (emphasis added)
>
> **I# 329 (Feb 1988):** The 1988 guide of physicians' *Current Procedural Terminology* (CPT) fourth edition, *includes several important changes in radiology & nuclear medicine* […] CPT descriptive terms and identifying codes currently serve a *wide variety of important functions in the field of medical nomenclature*. This system of terminology is the most *widely accepted nomenclature for the reporting of physician procedures and services under government & private health insurance programs*. CPT is also useful for administrative management […] In an effort to keep up with the most current "state of the art", the AMA revises and publishes CPT on annual basis. R. Songe and M. Lapyowker, both ACR members, are part of the editorial panel & CPT advisory committee. According to Lapayowker, *also chairman of the coding & nomenclature committee of the ACR*, the following revisions have been published: (e.g., 72141 Magnetic Resonance imaging, spinal canal & contents cervical; 72196 Magnetic Resonance imaging pelvis). (emphasis added)

Being able to fit the new devices in the "used" categorical systems through which exams and payments were funneled to physicians, specifically radiologists, was a critical win for the ACR. From this point on, NMR exams were considered radiological exams and therefore would require the signature of the radiology department's chair. The department would consequently get the respective interpretative and operative fees.

All the actions enacted by the ACR, including those in each of the stages just described, appeared to have transformed what seemed an insurmountable challenge when the ACR first became aware of the emergence of NMR devices. By mid-1988, NMR had become quite popular, dethroning ionizing radiation technologies as the most important technology in the community, but most importantly for the ACR (and radiologists), they were incorporated seamlessly into the technological armament inside most "diagnostic radiology departments" as shown by the following evidence:

> **I# 339 (May 1988):** A survey of hospital diagnostic radiology departments found that *the vast majority of the largest hospitals (400 beds or more) have CT, nuclear medicine scanners, MR, ultrasound equipment*, and that such diagnostic equipment was also used in a small percentage of hospital with under 100 beds. The survey conducted by ACR's Committee on Practice Management, under the Commission on Radiologic Practice, queried 7,110 hospital nationwide (60% response rate). Of the response, 98% indicated that these technologies were mainly located in the *diagnostic radiology* department. (emphasis added)

This concludes the description of the framework developed by the methodology and gathered data as described before. However, before moving to the initial exploration of the related "why" question, it seems important to describe some additional analysis that I performed. I used quantitative analysis (gamma analysis), testing whether the structure of the event sequence matches the theoretical model derived from the data analyzed. This technique, according to Poole and colleagues (2000) is appropriate for use with simple unitary developmental models (exactly the type offered by the framework derived from the inductive analysis just described). The results of this analysis are shown in Figure 25.

Poole and colleagues (2000: 251) note that "gamma diagrams provide a simple phasic description that allows for visual examination and comparison of sequences." In this particular case, the analysis provides support for the qualitative model developed inductively, uncovering four distinctive and clearly separated phases. Further analyses escape the scope of this particular stage in the development of this investigation.

Considering the framework described as a whole, the initial "how" question driving this research seems to be answered. The ACR did not fall into any of the inertial traps described in the traditional technology and organizations literature. This organization used rhetoric strategies, re-crafting the meaning of the new disruptive technology to the meaning that benefited its main constituents (the radiologists) but also that shaped the development of the technology and actively compelled its members into action. Perhaps, in this multiplicity of actions, aimed to influence multiple audiences, is where the ultimate success of its action lies. However, before moving to the implication of these findings, centered on how the ACR responded effectively to the creation, development, and commercialization of NMR devices, I present below some initial ideas on the second research question of this investigation: why was the ACR able to adapt to the emergence of NMR?

Exploring the "Why" Question

Taken together, all the actions enacted by the ACR, its members, and its commissions and committees, as described by the framework developed here, portray an organization that did not merely react, fail to react, or react ineffectively in terms of timing or commitment to change when faced with a disruptive technology. On the contrary, this framework exposes a highly adaptive entity that proactively scanned the environment and took a wide variety of actions to ensure that the new technology would not negatively affect the organization or its main constituents, the radiologists. Why this organization was effective in its response to this new disruptive technology is a question that has been answered partially by explaining how the ACR was able to normalize and make the new technology fit into institutional structures that benefited its main constituents.

However, the methodology adopted in this investigation also allowed me to consider this question by comparing the structure of the events in the sequence file with implied structures of four ideal "motors of change," (Van de Ven & Poole, 1995) developed from four different theoretical frameworks explaining change: life cycle theory, teleological theory, dialectical theory, and evolutionary theory.

If the event structure uncovered by this investigation is contrasted with these ideal models, one could argue that this structure fits soundly with the one describing the teleological motor. According to Poole and colleagues (2000: 85), an event structure fitting with this change motor would meet the following conditions:

1. An individual, or group, exists that acts as a singular discrete entity that engages in reflexively monitored action to construct and share a common end state goal.
2. The entity may envision its end state before or after actions it may take, and goal(s) may be set explicitly or implicitly. However, the process of social construction or sensemaking, decision making and goal setting must be identifiable
3. A set of requirements and constraints exists to attain the goal and the activities and developmental transitions undertaken by the entity contribute to meeting these requirements or constraints.

Additionally, the cycle was represented by this ideal motor: "(1) Search/Interact; (2) Set/Envision Goal; (3) Implement goals; (4) Dissatisfaction" (Poole et al., 2000: 61/66), which also fits quite nicely the four-stage model developed from the event structure studied in this investigation.

However, knowing that this process is driven by a teleological motor only seems to offer an incomplete answer—especially if one does not consider why the ACR had the impetus to take on this taxing task that could not necessarily be expected to succeed. Some organizational scholars have even argued that organizations would actively resist any adaptive effort because it goes against deeply rooted internal and external categories or identities that insiders and outsiders to these organizations try actively to defend (Brower & Abolafia, 1995; Humphreys & Brown, 2002; Tripsas, forthcoming).

Perhaps the impetus for change comes from exactly the same identity these and other authors single out as the potential inertial force impeding organizational adaptation. If one accepts that the organizational identity of the ACR is linked tightly to the professional identity of its members, perhaps defending that identity from such a threatening technology would energize everyone inside the ACR. As Selznick (1949, 1957 [1984]) puts it, normalizing NMR might have meaning for these members beyond the technical task at hand. It would be infused with value! These actors would see these tasks as a moral imperative.

Assessing whether this is the case goes beyond the scope of this project, but it seems important to note that consistent evidence within the data collected seems to support this exploratory idea.

> **I # 53: (Annual Meeting, Chairman of the Board, Dr. John Harris)** I think *it is important for the College to address itself to self-evaluation and a redefinition of its purpose & role*. The College has grown like a "cottage" industry. Suddenly, we are confronted with the problems of the '80s with "turf" (territorial and clinical prerogatives) being one of the most sensitive and complex. […] The College has to get about the business of *defining itself as the lead agency in radiology. it should be the college. it should be the sentinel in socio-economic matters and the "point" organizations*. It is fine that other societies have recognized that the College is, but now *we have to prove that we are. We have to deliver that responsibility*. (emphasis added)

> **I # 74 (William Seaman, Annual Meeting):** A most vexing problem that seems to be growing in scope and complexity is the *increasing encroachment into our specialty by non-radiologists* […] we must continue to strive for excellence and continue to probe that, as far as medical imaging (not just x-ray imaging) is concerned, we can do it better. We must expand our public relations program so that the public is aware of what we are, what our training has been, and what we do. We must convince the public and our colleagues that we are qualified to produce and interpret medical images. […] Education is one of our most potent *weapons in our jurisdictional battles with other specialists*. (emphasis added)

> **I # 133: Annual Report to the Membership (Chairman of the Board, Dr. John Harris):**NMR is predicted to have an impact upon medicine that will compare to, or even exceed, that of the discovery of x-rays in 1895. *It is also likely to render thousands of practicing radiologists "obsolete"* because of the new body of knowledge that NMR introduces into our specialty.[…]. *The college must constantly advance & defend the concept that these and other imaging procedures, whether or not they involve ionizing radiation, are procedures of the specialty of radiology*. […] If these agencies are *permitted to ignore this charge*, then in my opinion, radiology as it exists today will be a thing of the past in the not-too-distant future. I cannot emphasize the importance of this concept strongly enough. (emphasis added)

> **I # 237: Annual Meeting (Chairman Marasco)** Retaining the presence, proficiency & profitability of radiology in a highly competitive deregulated environment are major issues facing radiology today […] the profession faces increasing dependence on new technology to operate business and deliver service […] radiologists *must invest* more heavily in technology early on in this game and stay in the leading edge of new developments. If they fail behind in their technological investments, they will find it increasingly difficult to recover […] Throughout the specialty, there remain people who stubbornly resist the idea of change. ACR members must be convinced that *if radiology is to remain intact* as a specialty, it has to deal with the world as it is, not as it used to be. Phase 1 is to recognize the scope of the changes that confront radiology. Phase 2 involves the creation of *new and innovative ways to turn those changes to radiology's advantage. To do this, radiologists must be unified. The ACR is the vehicle for this unity* […]. (emphasis added)

Without a deeper analysis it is impossible to assess whether and how the professional identity of radiologists might have helped to energize the ACR and its members in their battles to normalize the new disruptive technologies. Perhaps, this could be a worthy next step for those interested in gaining a deeper understanding of how professional associations can influence the evolution of key technologies embedded in their professional work.

CHAPTER VI: CONTRIBUTIONS, LIMITATIONS, AND FUTURE RESEARCH

Changes in technology have affected our lives and the lives of those around us significantly, at least in the last few decades (Edwards, 2000; Song, 2009). Particularly within the organizational studies field, a myriad of studies have shown that organizations are also affected significantly by these changes in technology (Anderson & Tushman, 1990; Christensen, 1997; Christensen & Overdorf, 2000; Cooper & Smith, 1992; Kaplan *et al.*, 2003; Laurila, 1998; Rosenbloom & Christensen, 1998; Sull, 1999; Tripsas, 1997). That is why enhancing our knowledge of how organizations respond to technological changes is a worthwhile endeavor.

Specifically, when these changes in technology can be described as disruptive or discontinuous (Ehrnberg, 1995; Gatignon *et al.*, 2002), consistent empirical research has illustrated that organizations within the communities in which those technologies are embedded tend to suffer deep, negative performance consequences, and many times even complete demise (Christensen, 1993; Hill & Rothaermel, 2003; Tushman & Murmann, 1998; Tushman *et al.*, 1986).

Additionally, insights from two research streams have shown that the communities of organizations in which these technologies are embedded do not merely react to these changes, but they actively shape this process (Rosenkopf & Tushman, 1994; Rosenkopf & Tushman, 1998b; Tushman & Murmann, 1998; Tushman & Rosenkopf, 1992; Van de Ven, 1993; Van de Ven & Garud, 1989, 1994). These communities are formed by a closely interrelated group of entities including “competing organizations, professional societies, suppliers, customers, and governmental units”(Tushman & Rosenkopf, 1992: 343).

Taken together these works, however, have not paid too much attention to how particular organizations beyond those producing the technology respond to technological changes. Perhaps, that is the reason behind Tushman’s call for more investigations on this topic when noting that “we need to know more about how interactions between competing organizations, professional societies, suppliers, customers and governmental units shape technological evolution” (Tushman & Rosenkopf, 1992: 343).

This investigation addresses, at least partially, this theoretical gap and therefore contributes to the literature focused on organizations and technologies by starting to explore how a different type of organization, the American College of Radiology as a professional organization, within a specific community responded to a disruptive technological change (the emergence of NMR devices). This investigation also contributes to this research by exploring a “how” question and by developing a process model of effective response to these technological changes. This approach is unique within this literature, since most previous investigations have focused on “what” questions and developing insights on specific characteristics or organizational variables that explain certain behaviors of the firms under study. Third, this investigation contributes to the overarching organizational study literature by using a process-centered approach, a research methodology that has not been used much when studying specific organizational responses to technological discontinuities. Finally, this project also contributes to the literature on adaptation and inertia of organizations facing technological discontinuities by offering insights on a successful response to these types of technological changes. This is not a minor contribution either, as most of the previous investigations within this stream have portrayed inertial forces as almost inescapable and, therefore, successful adaptation as an unattainable objective for these entities. Balancing the evidence toward considering effective change as less unlikely could be an important step in the right direction. However, in addition to these general contributions to the organizations and technology literature, this investigation also adds specific theoretical contributions to this and other research streams.

Specific Contributions and Future Research Linked to the Organizations and Technology Literature

The model described in the previous chapter developed from the analysis of the data gathered provides several insights for this specific research stream. First, it shows how a professional organization effectively responded to a disruptive technological change. This framework exposes a highly adaptive entity that scanned the environment and took a wide variety of actions to ensure that the new technology would not affect negatively the organization or its main constituents. The process unveiled by this framework is one driven by a teleological motor, with the ACR actively shaping the sense-making process of its members and many of the other organizations participating in the technological community in which diagnostic imaging devices were embedded. Researchers interested in these issues could elaborate on the dynamics of organizational change and response to technological discontinuities by exploring alternative contexts or alternative professional associations. In particular, within this same context, it could be interesting to revisit the adaptation efforts that the ACR and other community members went through when CT scan devices emerged. This would give an interesting contrast to this study, considering that CT scanners' inner technology were at the center of the knowledge base of radiologists and incumbent producers, but evidence shown here seems to hint that it might have been a challenging time for many of the same organizations studied here.

Second, this model can have at least two potential implications for the commonly studied producers of technology. First, if one accepts that professional associations may be influential actors during technological change processes, it would be convenient for producers of technology to associate themselves with these types of organizations or at least to observe their actions in order to predict or react to changes in policies, practices, or institutions generated by these organizations. As a final point for these other organizations, producers would be well-advised in trying to proactively participate in the process of technological evolution rather than only trying to produce the best technical or value proposition through their design or architectural choices. The model uncovered here stressed the importance of institutional rather than technical or economical competence when succeeding in responding to technological changes. This also suggests another potential path for future research. In this case, I would argue that researchers in this stream could gain valuable insights by applying the same methodology employed here to study the ACR, to study the process by which an incumbent producer, such as General Electric in this particular context, successfully responded to a disruptive technological change.

Third, the framework developed in this project highlights the effectiveness of the normalization efforts led by the ACR, in terms of not only crafting and re-crafting of community-wide cognitive schemas but also in terms of policies and the practice of medicine associated to the new devices. This ability of the ACR to reshape institutionally-infused categories could open up a completely new set of questions in this research stream given that, until now, few scholars have questioned the power of categories. This is demonstrated partially by the success of a set of investigations that portrayed changes in categories as almost impossible, and the main force behind unsuccessful adaptive efforts (Hannan *et al.*, 2006; Hannan *et al.*, 2003; Hsu & Hannan, 2005; Jacobs *et al.*, 2008; Pólos *et al.*, 2002; Zuckerman, 1999, 2000; Zuckerman & Kim, 2003; Zuckerman *et al.*, 2003). Future research, then, can try to define under what conditions or what specific characteristics of institutional environments facilitate or hinder the possibility of certain actors to re-craft central categories or other value-infused systems.

Finally, the theoretical framework developed here shows that entities that effectively respond to the emergence of disruptive technology did so not by merely responding to the challenge, but rather by proactively influencing the process, and even the evolution of the artifact itself. This could reinvigorate works trying to unveil how other community organizations can also influence technological trajectories. Not only specific (powerful, first-mover) producers or groups of producers could influence how a technology evolves. This investigation specifically shows how influential just one professional organization can be, and thus it may stimulate other researchers to continue with this stream and uncover how other types of organizations within these communities actively affect the evolution of technologies. Lastly, this investigation can also have some implications for other research streams. I discuss them in the next section.

Potential Contributions to the Other Literatures

The process model uncovered by this project also seems to create some potential contributions and insights to other research streams beyond the ones discussed above. First, it is evident in all the discussions describing each stage of this process of effective adaptation that the ACR was able to succeed in their plan to normalize the new technology by influencing the evolution of the institutional infrastructures that were changing around the new technology. This gives additional empirical evidence for those scholars who stress the importance of institutions during the emergence of new technologies (Darby & Zucker, 1996; Das, 1994; Garud & Rappa, 1994; Hargadon & Douglas, 2001; Orlikowski & Barley, 2001; Van de Ven & Garud, 1994). This model could be used as a stepping-stone by those researchers within this stream interested in elaborating on how institutions are changed to fit new technologies and practices.

This project could also have some interesting insights for those studying professions, particularly those interested in studying the influence of professions in different processes. I would argue that in contrast to some arguments stressing that the source of professional influence is their expertise, this project shows a case in which expertise was the weakest potential source of influence for radiologists (Abbott, 1988; Evetts, 2006). This case supports the idea that expertise plays little if any role and that the radiologists' advantage resided in their relationships and positions within key regulative bodies and legislative circles.

Finally, this project could also have some impact on those thinking about organizational change and adaptation in general. The case of the ACR reminds us that sometimes, or at least for some organizations, change and adaptation depend heavily on controlling, or at least co-opting, key parts of an environment (Pfeffer & Salancik, 1978 [2003]; Selznick, 1949) and not by merely relying on the ability to change internal structures, practices, or leaders.

Limitations

This study has some limitations, mainly coming from the methodology chosen and some of the choices made during the process of interpreting the evidence collected. The first limitation of this investigation resides on its inability to study the process of organizational response as it unfolded. This is a problem because one loses the opportunity to observe participants' reactions, their sense-making process, and to "judge immediately how adequate [one's] data is and to follow up on questions in uncertain areas"(Poole *et al.*, 2000: 136). Relying on archival data implies that one "must make do what has been preserved" (Poole *et al.*, 2000: 137) and that "knowing how things turn out can bias one's perception and interpretations" (Poole *et al.*, 2000: 138). These limitations of the archival approach are partially a consequence of the phenomenon under study, as technological discontinuities can be identified only a posteriori of their occurrence. However, I explicitly tried to reduce the impact of these problems by relying on multiple sources of data and, perhaps more importantly, by considering especially those documents that were produced by the participants or sources of data in which the voice of the participants were a central part to the evidence offered by the author/s.

The second limitation of my interpretations and framework is that I relied on one layer of coding, thus, reducing "rich qualitative data to a single dimension of meaning" (Poole *et al.*, 2000: 145). In other words, I relied heavily on Abell's (1987) narrative scheme, rather than allowing for multiple, intertwining narratives, as suggested by Abbott (1990). This choice could hide, for instance, other change motors that are less evident if one only focuses on the actions of the ACR. This is a weakness I minimized by actively reading and gathering data from multiple sources and considering the voice expressed in the industry-wide journal. However, all these actions only reduced this risk and did not completely avoid the problem. I would argue, though, that this is a relatively minor problem if one considers that the main objective of this investigation was to analyze this process from the viewpoint of the ACR, while paying special attention to its actions.

Finally, the issue of external validity is always at hand, and this project is not different from any other in this respect. Can the insights uncovered here be translated to other technological discontinuities and other professional associations or organizations in general? This is a question that cannot be answered simply, but one that seems less important if one tries to focus on the theoretical-level insights rather than specific actions over specific occurrences (Huberman & Miles, 2002).

In closing this investigation, it seems important to stress that even though not all the questions related to this study have been answered here, at least one can be satisfied by making one small step forward in terms of how we understand complex organizational change processes. Future researchers reading and taking advantage of some of the insights developed by this project can do better by avoiding some of the drawbacks I have detailed here. Thus, one could argue, that at least this project contributed to the constant advancement of organizational theory by alerting those imagining or planning new studies about potential problems they may face.

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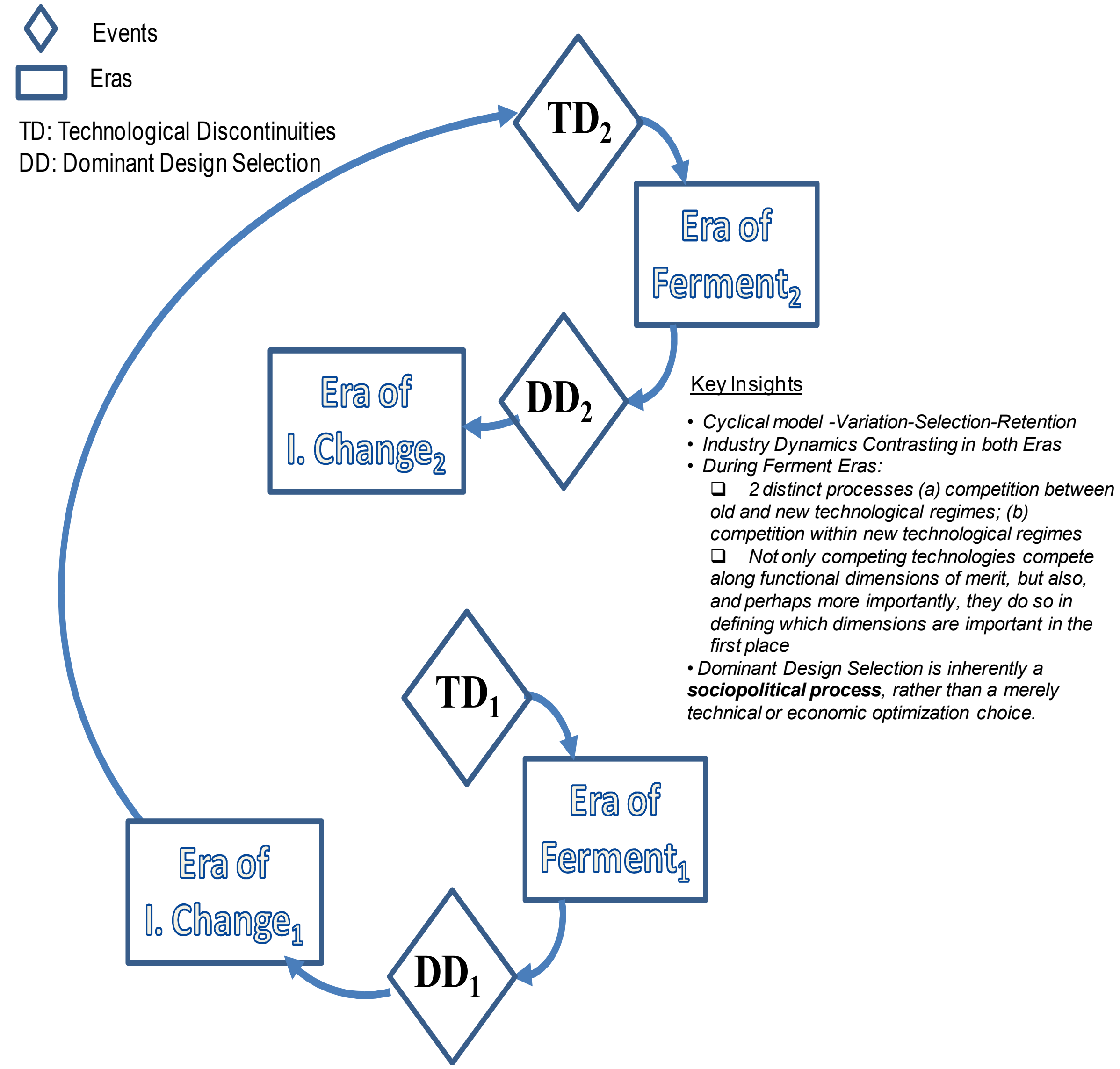
TABLES AND FIGURES

Figure 1: Tushman's Technological Evolution Framework



Key Insights

- *Cyclical model -Variation-Selection-Retention*
- *Industry Dynamics Contrasting in both Eras*
- *During Ferment Eras:*
  - ❑ *2 distinct processes (a) competition between old and new technological regimes; (b) competition within new technological regimes*
  - ❑ *Not only competing technologies compete along functional dimensions of merit, but also, and perhaps more importantly, they do so in defining which dimensions are important in the first place*
- *Dominant Design Selection is inherently a* ***sociopolitical process****, rather than a merely technical or economic optimization choice.*

Figure 2: Roentgen Operating One of His Early X-ray Machines

Figure 3: Examples of First Radiograph of a Human Hand

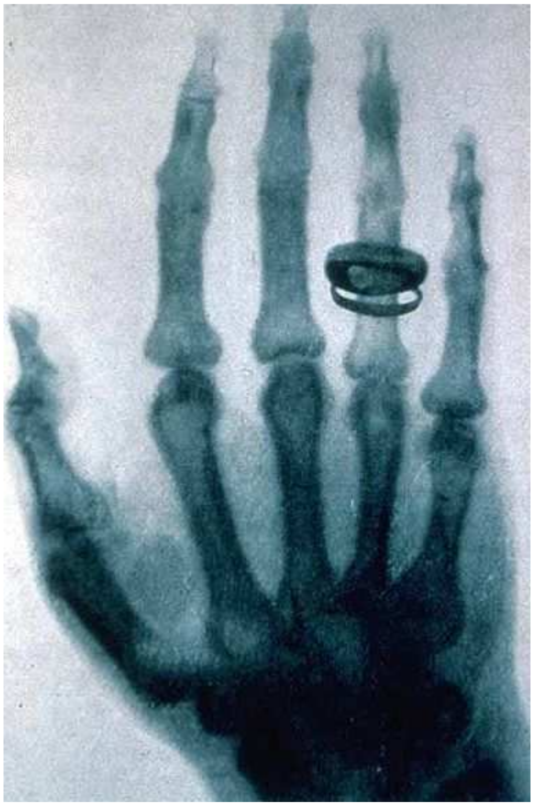


Figure 4: Newer X-ray Devices and Radiographs (Hand, Lungs)

(a) Typical X-ray Device Late 1940s

(b) Typical Contemporary X-ray Device

(c) Typical Contemporary Radiograph of Hands

(d) Typical Contemporary Radiograph of Human Chest

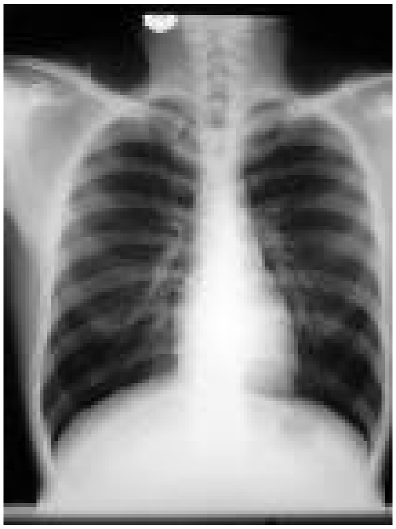
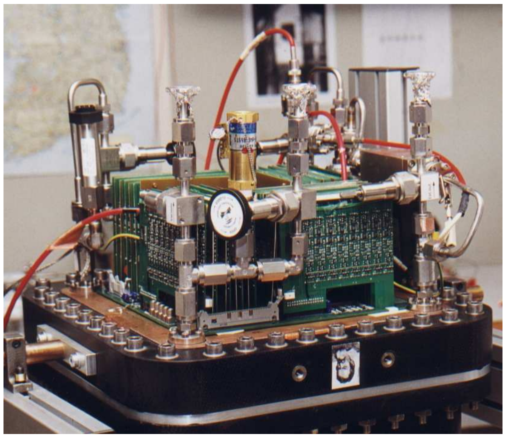


Figure 5: Gamma Camera Devices

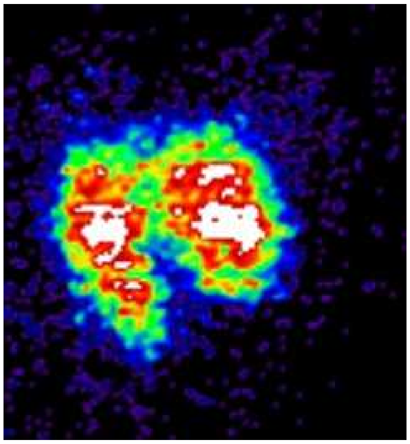
(a) Older Models



(b) Contemporary Model

Figure 6: Gamma Camera Images

(a) Older Image of a Human Heart



(b) Newer set of images on Lung Study

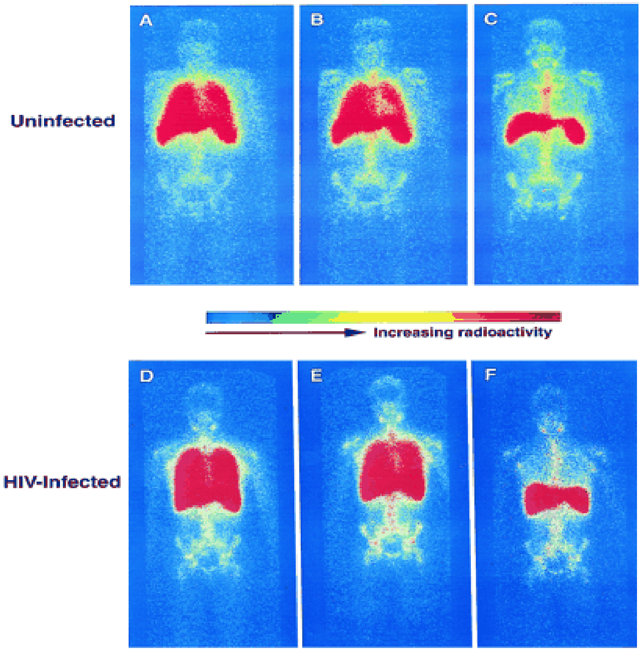
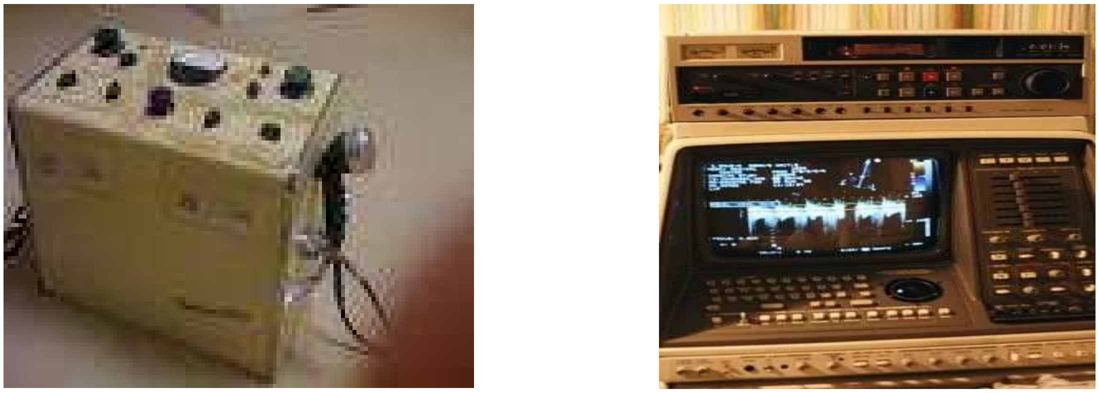


Figure 7: Ultrasound Devices



(a) Original Ultrasound Device

(b) Typical 1970s Ultrasound Device

(c) Contemporary Ultrasound Device

Figure 8: Ultrasound Images

(a) Typical Older Ultrasound Image of Human Fetus

(b) Contemporary 3D Ultrasound Image of Human Fetus

Figure 9: CT Devices

(a) Typical Late 1970s CT scan Device

(b) Contemporary CT scan Device

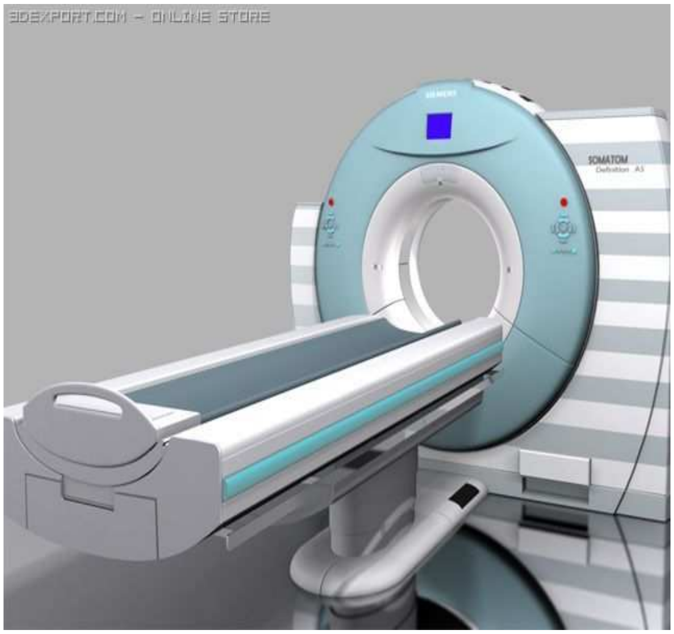
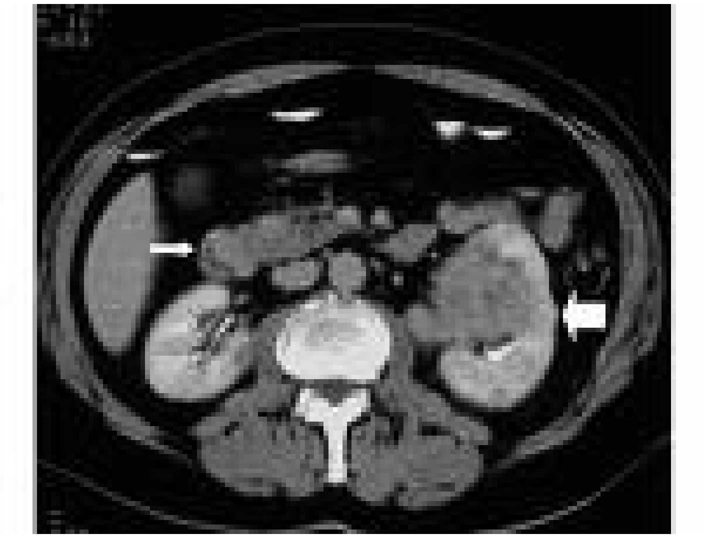


Figure 10: CT Slides Images

(a) Older CT Slide Image of the Abdominal Region



(b) Contemporary HD Slide Image of Human Lungs

Figure 11: Methodological Procedure

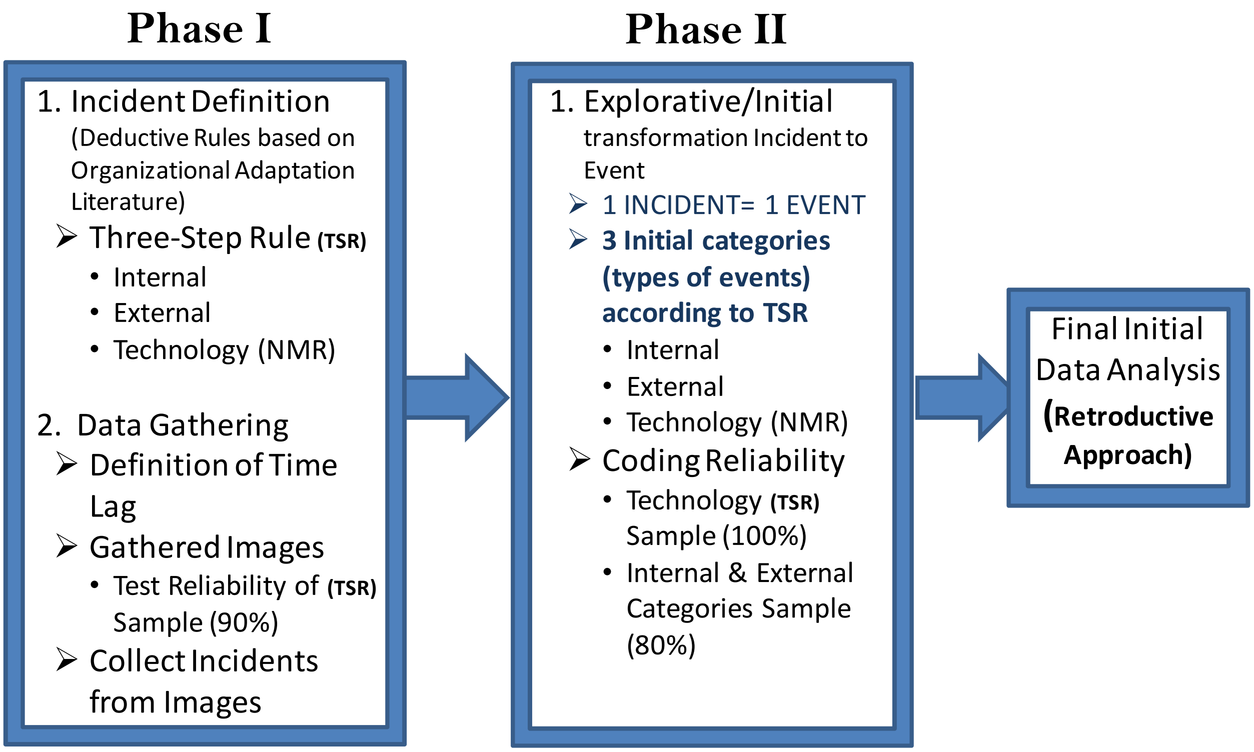


Figure 12: NMR Evolution & ACR's Data Evaluated & Gathered

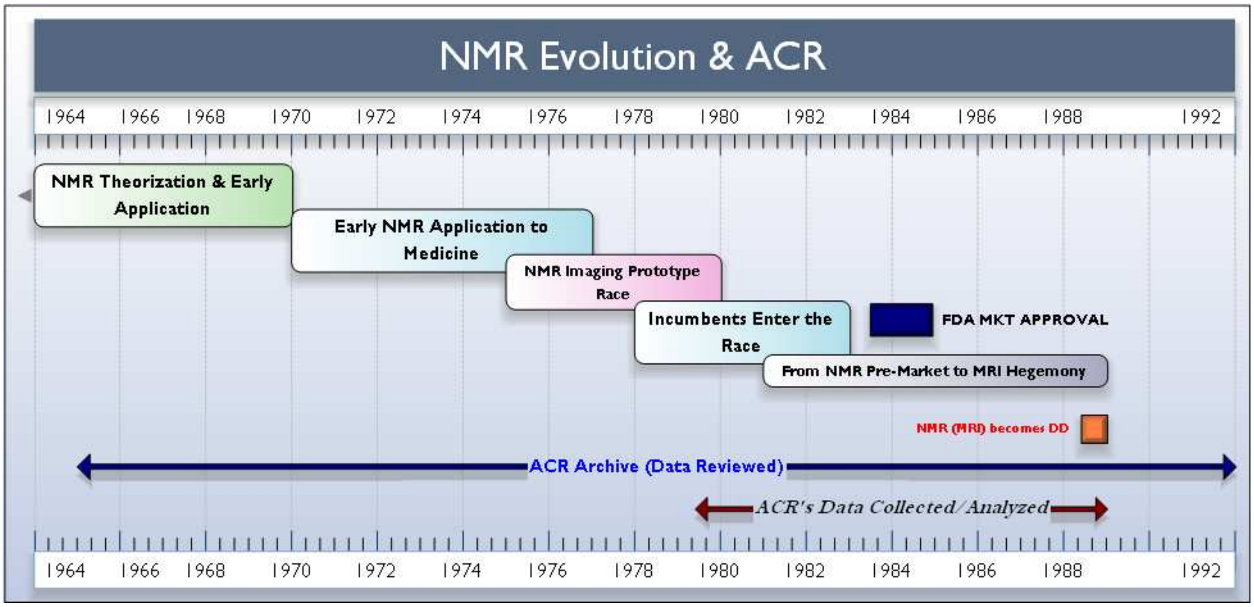


Figure 13: Temporal Sequence of Events by Type (Graph)

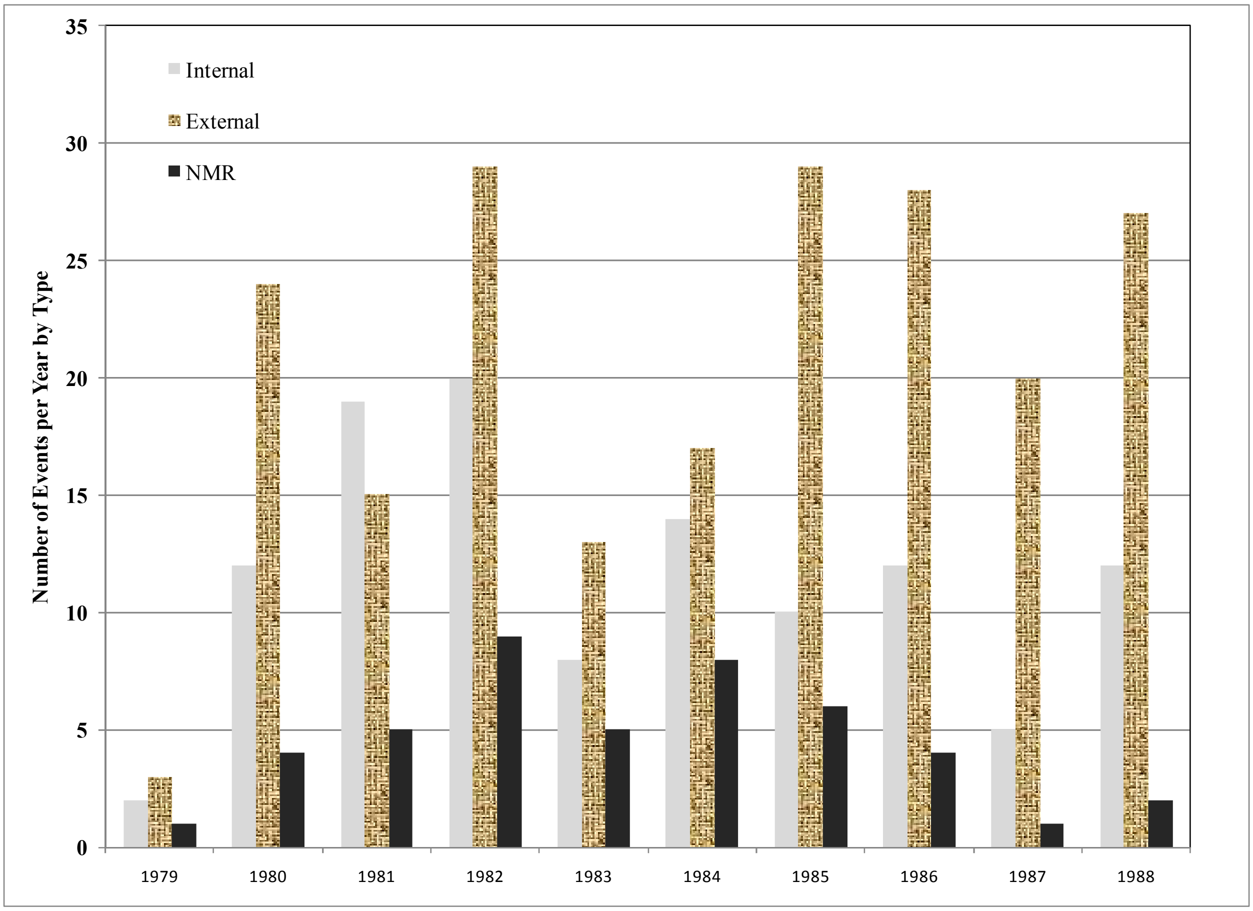


Figure 14: First Human Wrist Image Published Hinshaw et al. 1977 (Nottingham–U.K.)

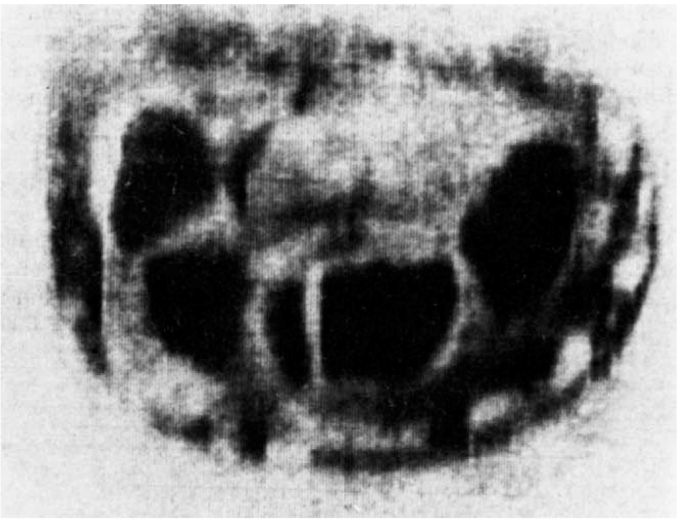


Fig. 1 An NMR image of the distribution of mobile protons in a thin transverse section through the left wrist of one of the authors (P.A.B.). The image is orientated as though the author were facing you with palm upward and was taken at the level of the distal tip of the anterior horn of the lunate. The thumb was held close to the palm causing the general outline to differ slightly from the drawing in Fig. 2. Dark areas in the image indicate regions that contain high concentrations of mobile protons such as the marrow in the carpals and subcutaneous fat. Light areas indicate the presence of tissue with few mobile protons such as tendons, nerves and solid bone. Blood in the veins and arteries is light due to its motion during the imaging process.

Figure 15: NMR Image Published by Mansfield and Colleagues (Nottingham–U.K.)

a) Human Finger (1977)

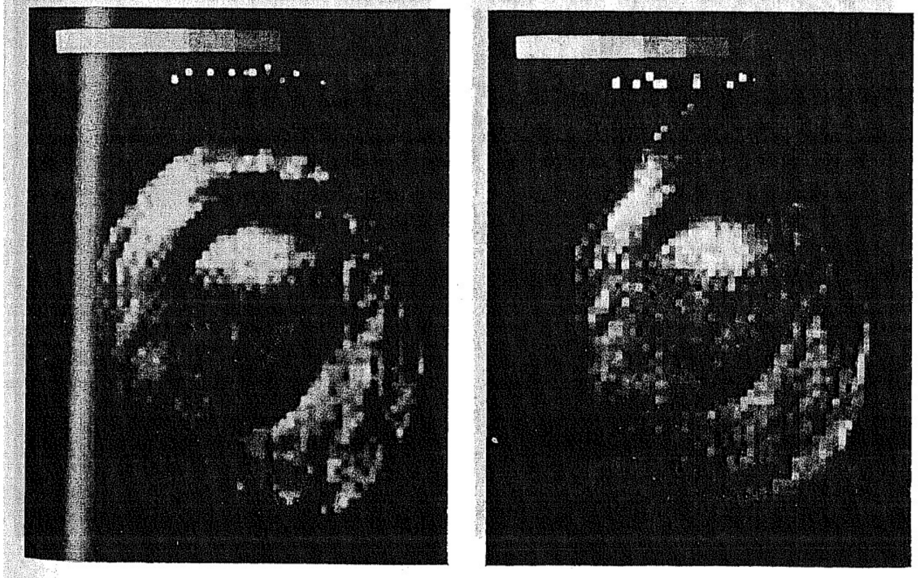


Fig. 5.

Colour versions of the finger images shown in Figs. 4A and B.
(A) The eight colours black through to white correspond to data levels 6–13. The delay time $\tau = 0.5$ sec.
(B) The eight colours black through to white correspond to data levels 2–9.
In both pictures, data falling outside the window limits are presented as all black or all white as appropriate.

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b) Cross-Section of an Abdomen (1978)

by Garroway *et al.* (1974). A slightly modified version of the

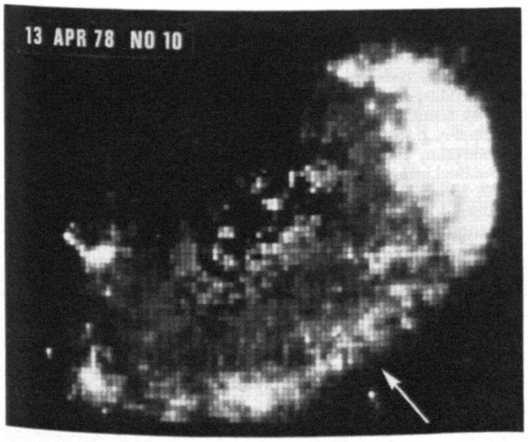

Fig. 1.

Cross-sectional line-scan NMR image through the abdomen at L2-3. Arrow indicates mid-line posterior. Left side lies to the left of the illustration. Bright zones correspond in general to high mobile proton content. See Fig. 2 for labelled details.

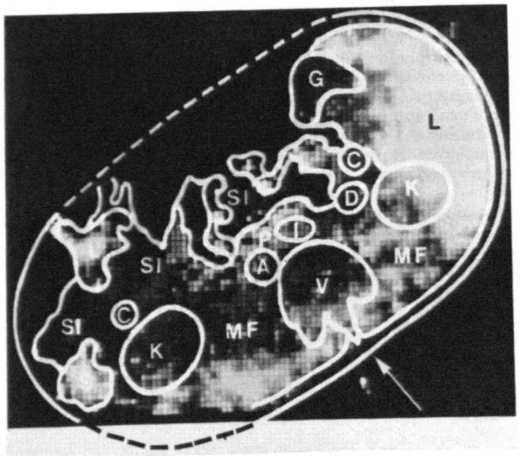

Fig. 2.

Labelled image of Fig. 1. A=aorta, C=colon, D=duodenum, G=gall-bladder, I=inferior vena cava, K=kidneys, L=liver, P=pancreas, S=spleen, SI=stomach and intestines, V=vertebra. Abdominal muscles and retroperitoneal fat (MF) are seen adjacent to the vertebra.

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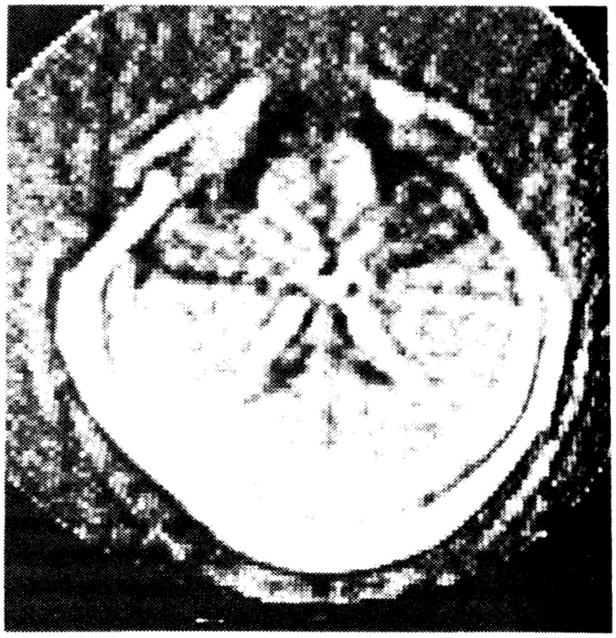
Figure 16: NMR Image Published by Young & Clow, 1978 (EMI R&D–U.K.)



Section through the head of Dr Hugh Clow of EMI's Central Research Laboratories imaged using nuclear magnetic resonance. Clearly visible (at the top of the picture) are the eye sockets and eyeballs and the ventricles in the brain (below centre, left and right)

Figure 17: NMR Image Published by Damadian & Colleagues, 1976 (U.S.)

Fig. 2. Cross-sectional video FONAR image of a live mouse, obtained with a 3-mm exploring spot. At the left is a photograph of the anatomical section for comparison. The heart is anterior in the photo, and the lungs, seen as collapsed white structures, fill the remainder of the thorax. The most intense proton signal in the FONAR image occurs in the region of the blood-filled heart. The dark fields in the upper half of the photo were generated by the hydrogen-poor air-filled lungs. The television raster is seen coursing through the image. Overlap artifacts appear in the image as bright, vertical and horizontal lines and are due to imperfect positioning of adjacent mapping squares.

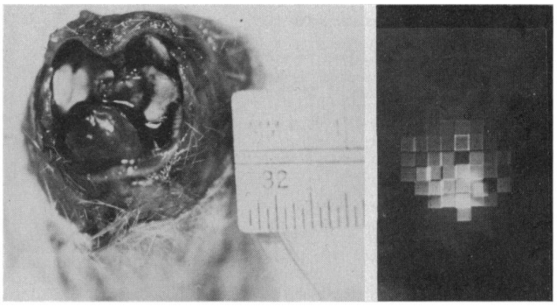


Figure 18: The Indomitable (Damadian's First NMR Device)

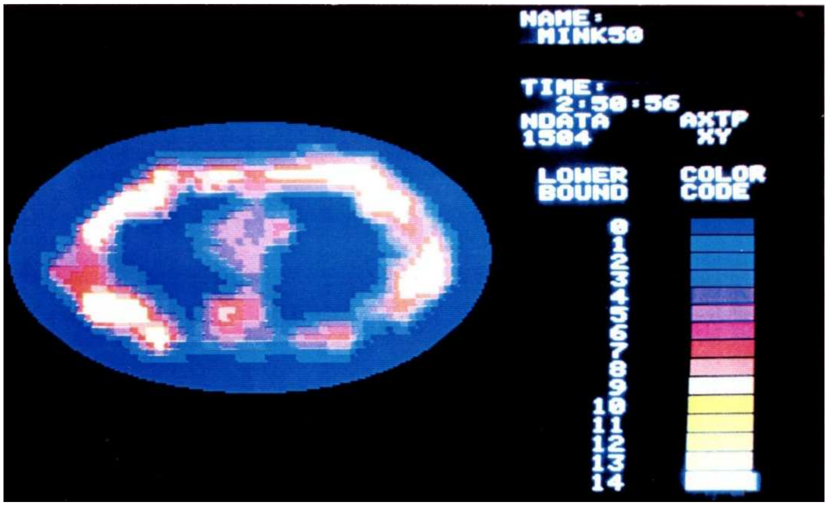
(a) Damadian team during the early construction of the Indomitable

(b) Raymond Damadian next to the Indomitable at the Smithsonian Museum

© Fonar Corporation

Figure 19: NMR Image Published by Damadian & Colleagues, 1976 (U.S.)

(a) Original image submitted to journals preserved by Damadian



b) Damadian team during the early construction of the Indomitable

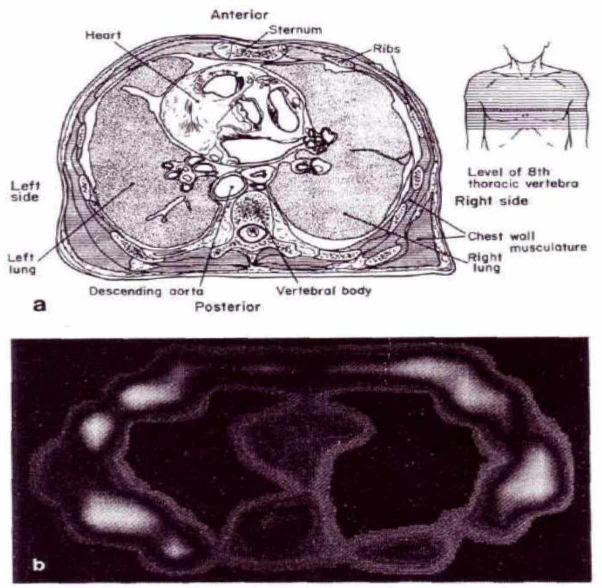
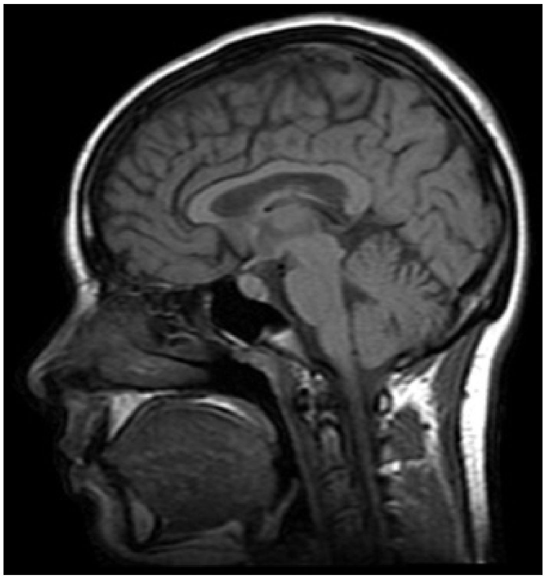


Fig. 2. (a) Schematic of the human chest at the level of the eighth thoracic vertebra, (b) FONAR cross-section of the live human chest at this level. Proton-signal intensity is coded, with black assigned to zero signal amplitude, white assigned to signals of strongest intensities, and intermediate grey scales assigned to intermediate intensities. Top of image is anterior boundary of chest wall. Left area is left side of chest. Proceeding from anterior to posterior along midline, the principal structure is the heart seen encroaching on the left lung field (black cavity). Left lung field is diminished in size relative to right lung (black cavity to right of midline), as it should be (see (a)). More posteriorly and slightly left of midline is a grey elliptical structure corresponding to the descending aorta. In the body wall, beginning at the sternum (anterior midline) and proceeding around the ellipse, alternation of high intensity (white) with intermediate intensity (grey) could correspond to alternation of intercostal muscles (high intensity) with rib (low intensity) as shown in (a). The image is a black-and-white photo of the original 14-color video display

Figure 20: Newer NMR images (MRI Scans)

(a) Contemporary MRI Slice Image of Human Head



(b) Contemporary MRI Slice Set Images of Human Head

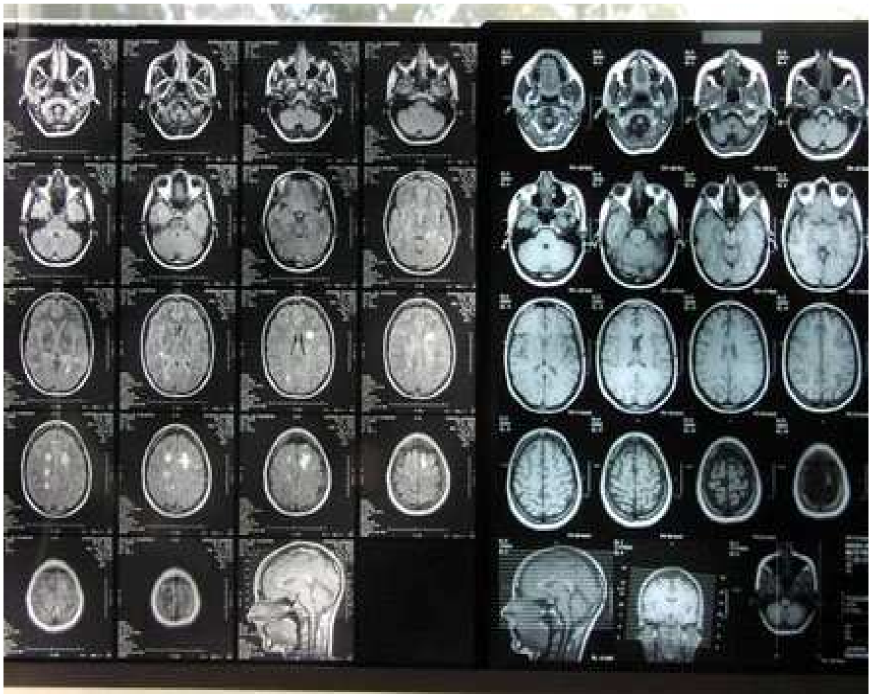
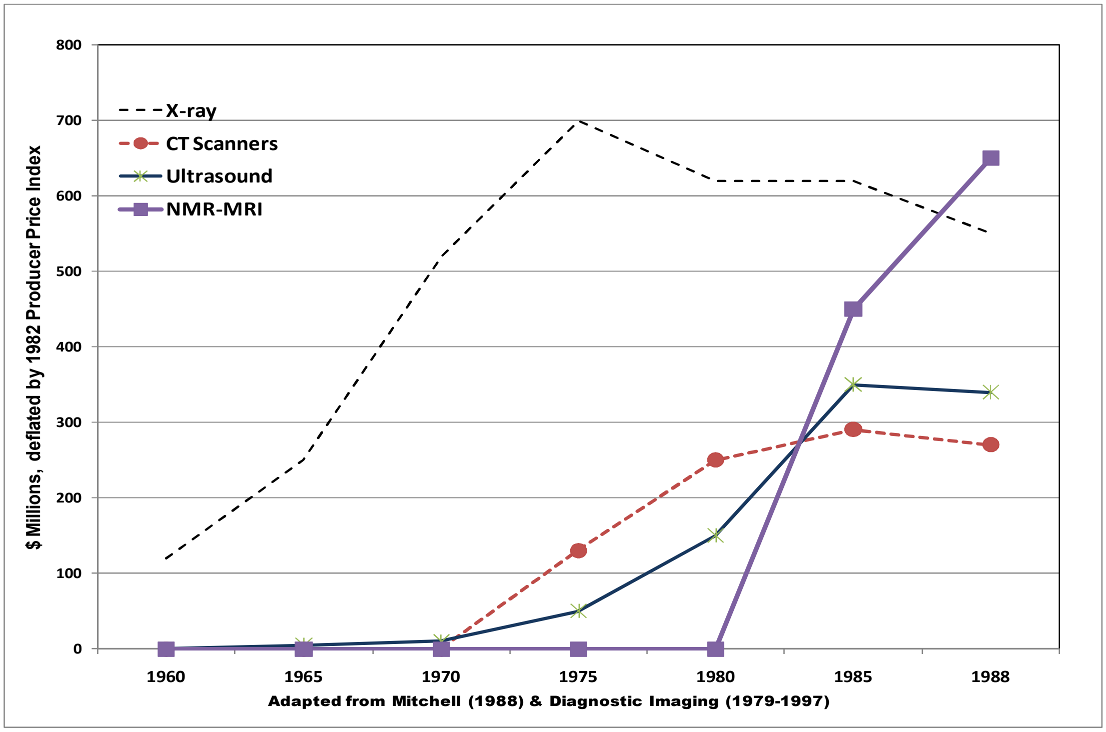


Figure 21: Evolution of Diagnostic Imaging Technology Sales by Type

a) Sales in Dollars by Technology



b) Sales as Market Share by Technology

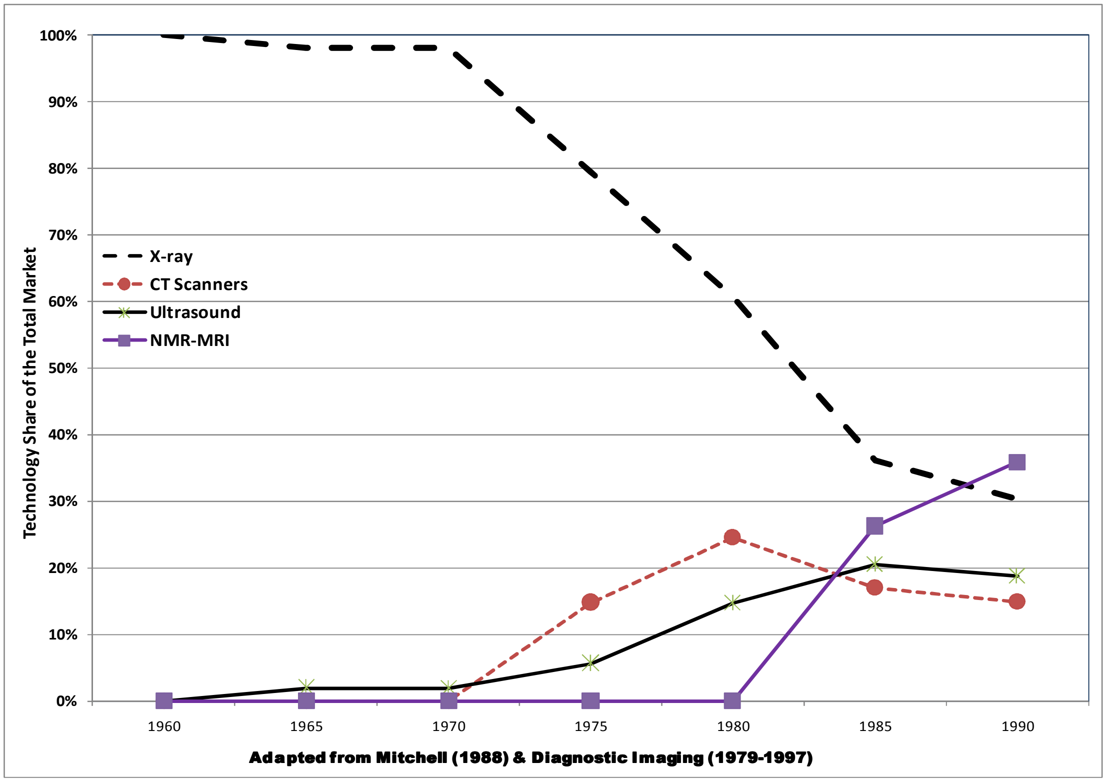
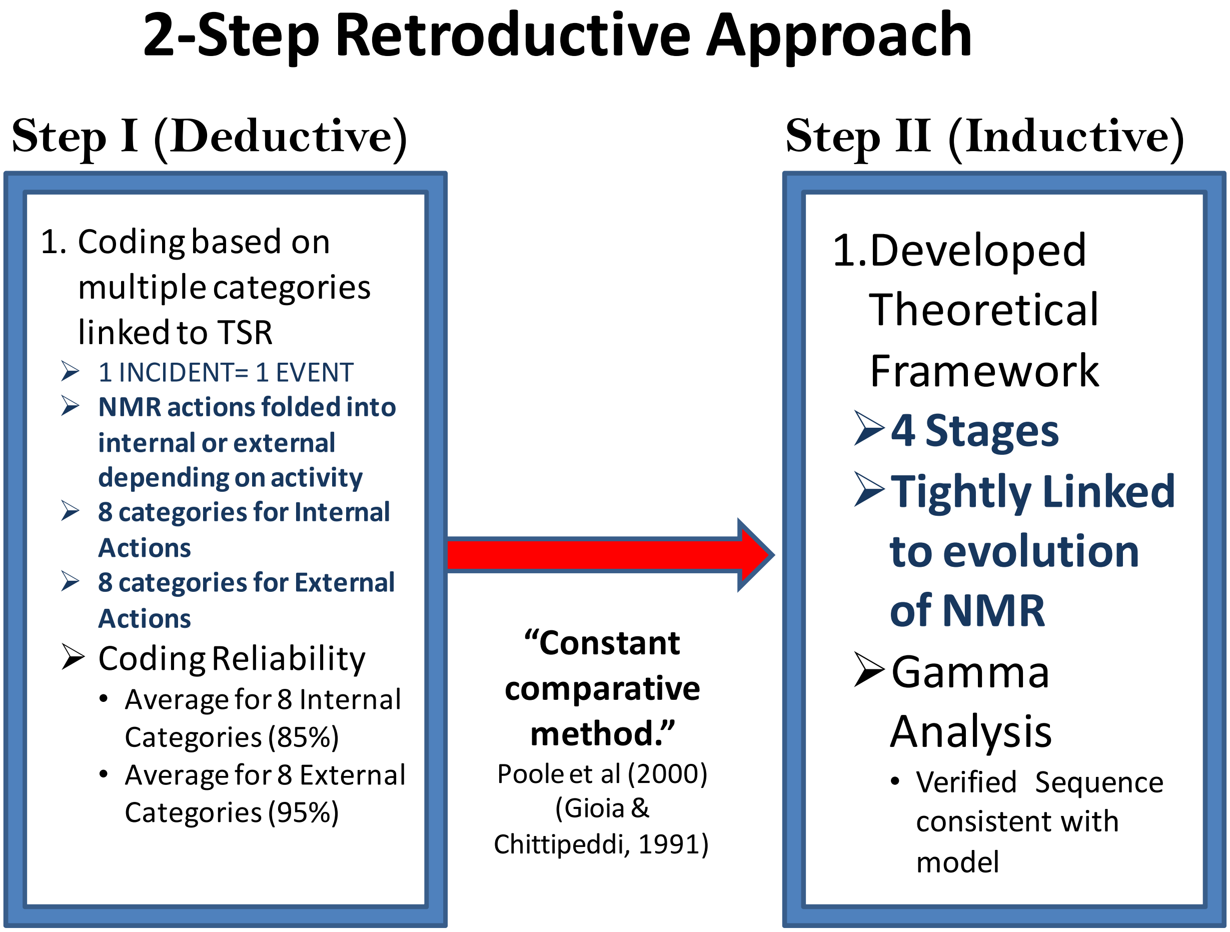


Figure 22: Two-Step Retroductive Process from Incidents to Theoretical Model



2-Step Retroductive Approach

Step I (Deductive)

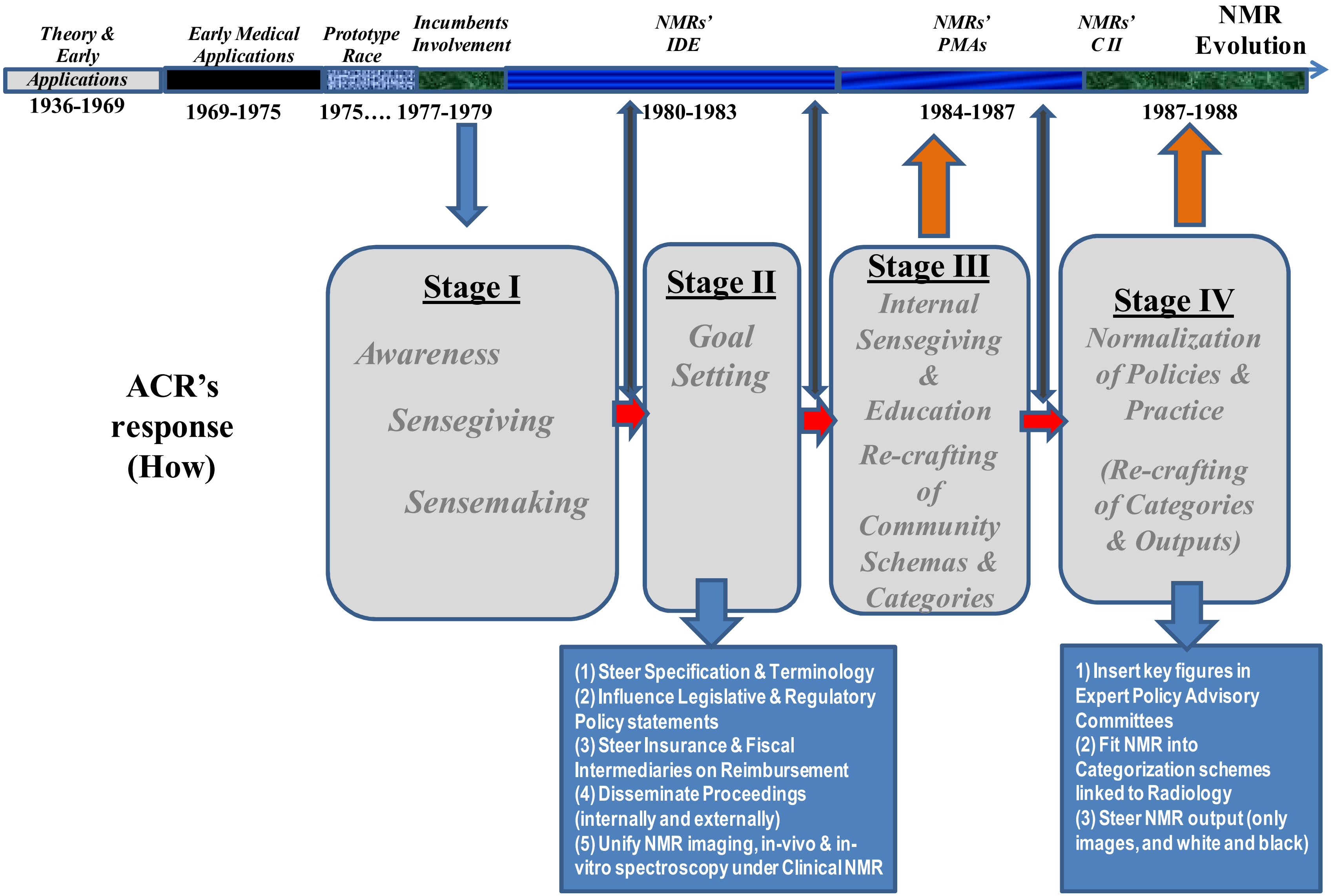
1. Coding based on multiple categories linked to TSR
   - ➢ 1 INCIDENT= 1 EVENT
   - ➢ **NMR actions folded into internal or external depending on activity**
   - ➢ **8 categories for Internal Actions**
   - ➢ **8 categories for External Actions**
   - ➢ Coding Reliability
     - Average for 8 Internal Categories (85%)
     - Average for 8 External Categories (95%)

"Constant comparative method."
Poole et al (2000)
(Gioia & Chittipeddi, 1991)

Step II (Inductive)

1. Developed Theoretical Framework
   - ➢ **4 Stages**
   - ➢ **Tightly Linked to evolution of NMR**
   - ➢ Gamma Analysis
     - Verified Sequence consistent with model

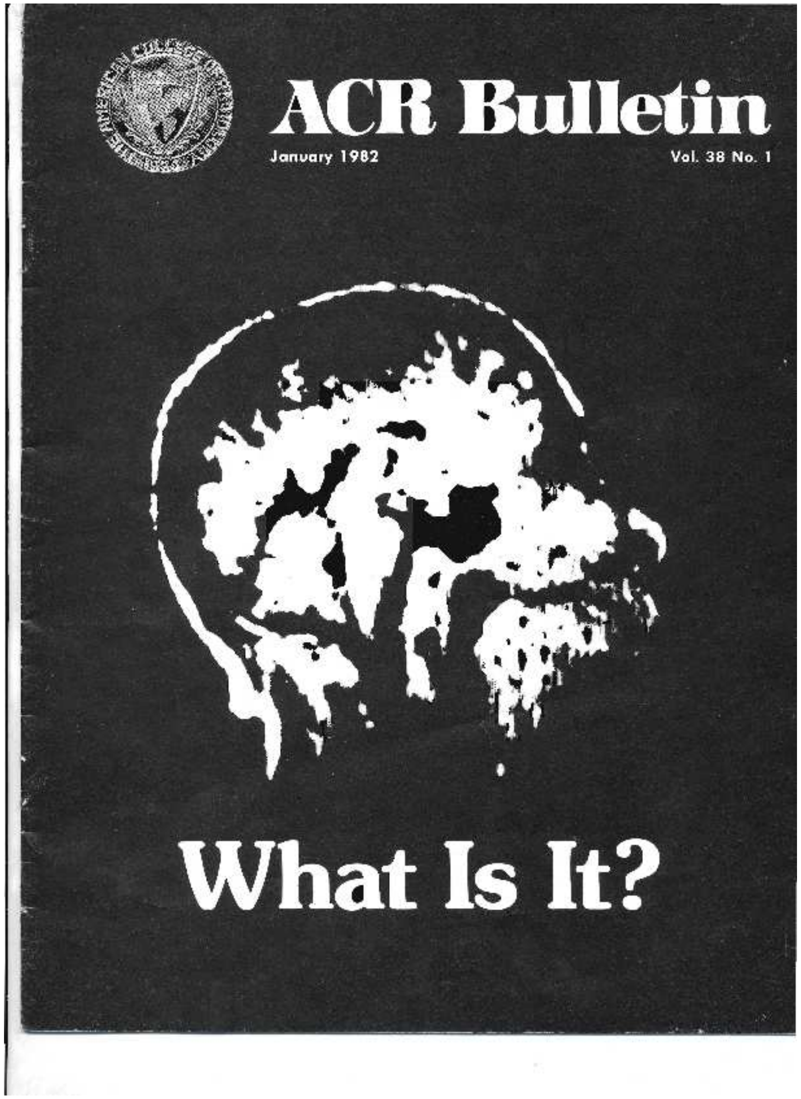
Figure 23: Theoretical Model Addressing How ACR Effectively Responded to NMR



(1) Steer Specification & Terminology
(2) Influence Legislative & Regulatory Policy statements
(3) Steer Insurance & Fiscal Intermediaries on Reimbursement
(4) Disseminate Proceedings (internally and externally)
(5) Unify NMR imaging, in-vivo & in-vitro spectroscopy under Clinical NMR

1) Insert key figures in Expert Policy Advisory Committees
(2) Fit NMR into Categorization schemes linked to Radiology
(3) Steer NMR output (only images, and white and black)

Figure 24: ***ACR Bulletin*** **January 1982 Images (Cover & Page 3)**



January 1982

Page 3

Special Report

It's NMR!

There's a new image in your future and now is the time to see it clearly. It's called NMR, or nuclear magnetic resonance, and its potential is astounding.

To enable radiologists to quickly grasp the use and importance of NMR, the ACR has established a Commission on Nuclear Magnetic Resonance, which is being chaired by Thomas F. Meaney of the Cleveland Clinic.

Dr. Meaney

"It is hoped that the Commission will provide the necessary information to ACR members as this new modality emerges," Dr. Meaney said in an interview with the ACR Bulletin. "Further, the Commission will act as a resource to health care providers and to policymakers as this modality moves into the clinical arena. Hopefully, the Commission will be able to avert many of the problems which arose during the introduction and clinical application of CT scanning."

An initial objective of the commission will be to evaluate present and future research and all clinical work to deter various clinical applications. Data collected within the next two years or more will be compared with that from other imaging modalities. Also, a prospectus on the basic technology of NMR is being developed and will be available to members by mid to late 1982.

Dr. Meaney said NMR problems fall within three groups:

1. Concern for obfuscating regulations and controls being hastily imposed by governmental agencies and health planners.

2. Accumulating sufficient scientific data to demonstrate the efficacy or lack of efficacy of NMR to study various organ systems and diseases.

"We've arrived at a technology that intuitively looks more exciting than CT, but we lack the data to back up this intuition," Dr. Meaney said.

3. Most manufacturers have not settled on the kind of product they will sell. There is a vexing lack of standardization. For example, there are two categories of magnets being used in research—resistive and super conductor (cryogenic). Companies conducting research on NMR are testing both types of magnets.

Dr. Meaney urges members to carefully follow the preliminary trials being conducted with NMR and to attend one or more of the many seminars that will be offered in 1982. Complete comprehension of NMR will permit the radiologist to act quickly to integrate it into the radiology department when the technology reaches the stage of clinical applicability.

While the physics of NMR will be strange to many radiologists, the image analyses will be easy for those skilled in interpreting CT and ultrasound studies, he explained.

Most of the clinical work with NMR has been done in the United Kingdom, principally at the University of Aberdeen, Nottingham University, and Hammersmith Hospital. Based on the early use of NMR in the U.K., Dr. Meaney said he and many other physicians believe the new technology will replace CT for neurological applications and probably for many body examinations.

Domestically, clinical studies are under way at the University of California San Francisco and Massachusetts General Hospital, which has a resistive magnet for head examinations. Clinical work will be started soon at the Cleveland Clinic, the University Hospitals in Cleveland, and the University of Pennsylvania.

Dr. Meaney noted that some of the non patient research has been done by nonradiologists, which may be a portent for the future use of this new imaging modality. It behooves radiologists to become NMR experts if they want to be at the forefront of its development and implementation.

Meanwhile, the committees that have been established and their assignments, which identify their objectives, are:

Committee on Investigational Resources, James L. Youker, chairman; objectives: (1) Identify and monitor potential sources for support of experimental and clinical investigations. (2) Interact with various committees of the Commission on the subject of investigational resources.

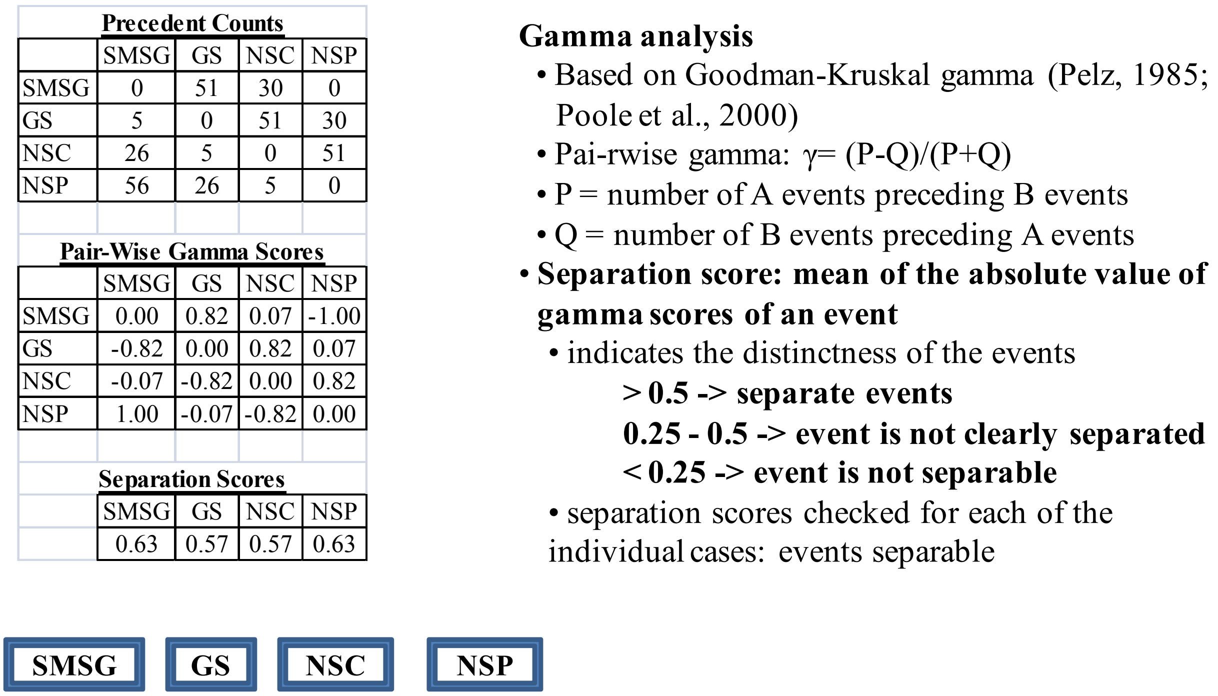
Committee on NMR Imaging Technology and Equipment, Alexander R. Margulis, chairman; objectives: (1) Identify the various NMR imaging technologies in use and in development. (2) Develop a common or uniform equipment specification terminology and attempt to persuade manufacturers to use standard terminology or otherwise define meaning of their specifications; (3) Translate the perceived or known advantages and disadvantages of various technologies and equipment into useable information for the radiological community.

Committee on Clinical Applications, Juan M. Taveras, chairman; objectives: (1) Monitor clinical investigation on NMR imaging and in vitro spectroscopy in the United States and abroad; (2) Identify the potential applications of NMR in various organ systems; (3) Develop methodologies for a dialog between clinical investigators in the field; (4) Communicate findings on a regular basis to the Committee on Government Affairs and the Committee on Education and Training.

Committee on Biological Effects, Thomas F. Budinger, chairman; objectives: (1) Provide information to the radiologic, industrial, and other publics regarding present knowledge on biological effects of NMR; (2) Monitor new information or evidence in the field and update #1; (3) Cooperate with federal and state agencies in the development of policies and standards for human subjects;

(Continued on page

Figure 25: Gamma Analysis for Four-Stage Model



Precedent Counts

	SMSG	GS	NSC	NSP
SMSG	0	51	30	0
GS	5	0	51	30
NSC	26	5	0	51
NSP	56	26	5	0

Pair-Wise Gamma Scores

	SMSG	GS	NSC	NSP
SMSG	0.00	0.82	0.07	-1.00
GS	-0.82	0.00	0.82	0.07
NSC	-0.07	-0.82	0.00	0.82
NSP	1.00	-0.07	-0.82	0.00

Separation Scores

SMSG	GS	NSC	NSP
0.63	0.57	0.57	0.63

Gamma analysis

- Based on Goodman-Kruskal gamma (Pelz, 1985; Poole et al., 2000)
- Pai-rwise gamma: $\gamma = (P-Q)/(P+Q)$
- P = number of A events preceding B events
- Q = number of B events preceding A events

- **Separation score: mean of the absolute value of gamma scores of an event**
  - indicates the distinctness of the events

    > 0.5 -> separate events

    0.25 - 0.5 -> event is not clearly separated

    < 0.25 -> event is not separable
  - separation scores checked for each of the individual cases: events separable

SMSG **GS** **NSC** **NSP**

Table 1: Technological Evolution within the Diagnostic Imaging Device Community

Technology	Phase I: Exploration*	Phase II: Development*	Phase III: Diffusion, Evaluation and Assessment*
X-Ray	1895–1905	1905–1940	1940–…
Gamma Camera	1934–1955	1955–1973	1972–…
SPECT	1934–1955	1955–1973	1973–…
PET	1934–1955	1955–1973	1974–…
Ultrasound	1937–1953	1954–1965	1965–…
CT	1961–1973	1973–1975	1973–…

Sources: (Blume, 1992; Kevles, 1997; Mitchell, 1988)
***Phases followed Blume (1992: 68)**

Table 2: Advantages, Drawbacks, and Frequent Uses of Imaging Technologies

	X-Rays	**Ultrasound**	**Nuclear Medicine**	**SPECT & PET**	**CT Scan**
Imaging Source	X-rays	Sound Waves	Radioactive Isotopes	Radioactive Isotopes	X-rays
Advantages	• Low Cost • Minimally Invasive	• Low Cost • Noninvasive • Real-Time Imaging	• Functional visualization • Helps define space-occupying tumors	• Functional visualization • Real Time Imaging • Images metabolism	• Speed • Scan Bones and Cartilage
Drawbacks	• Does not image some tissues or behind bones • Ionizing Radiation	• Does not image areas around the lungs • Low Resolution	• Poor anatomical definition • Significant radioactivity	• Time Consuming • Low spatial definition • Complex • Exposure to radioactivity	• High Cost • Limited Tissue Definition • Ionizing Radiation
Frequent Uses	• Broken Bones • Chest • Dental • cancer	• Fetus • Heart • Breast • Kidneys	• Brain • Kidney • Abdomen • Bones • Lungs • Soft Tissues	• Bone Cancer • Blood Flow (Heart, Brain, Liver) • Heart • Brain Mapping (PET)	• Blood Clots • Fractures • Emergency Room • Brain Tumors

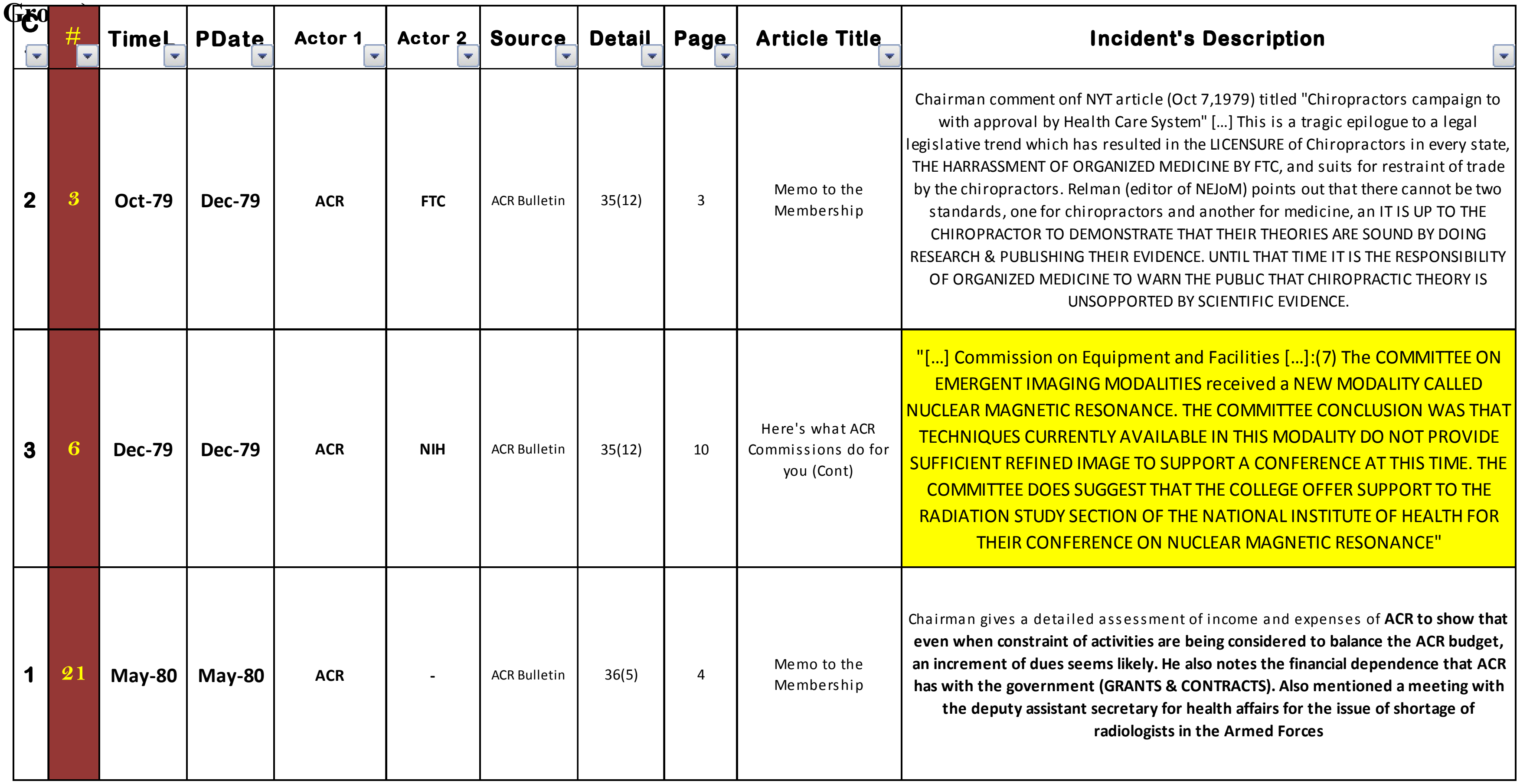
***Adapted from Kevles (1997: 225)**

Table 3: Non-Exhaustive List of Sources Used on Data Gathering Effort

Source	**Period Covered**	**Processes Covered**
Brecher & Brecher (1969)	1895–1965	Diagnostic Medical Imaging Community Evolution
Barley (1984) The professional, the semi-professional and the machines: The social ramifications of computer based imaging in radiology	1895–1983	Diagnostic Medical Imaging Community Evolution
Estrin (1990) The Medical Device Industry: Science, Technology, and Regulation in a Competitive Environment	1980–1989	Diagnostic Medical Imaging Community Evolution
Hamilton (1982) Medical Diagnostic Imaging Systems: Technology and Applications	1960–1980	Diagnostic Medical Imaging Community Evolution
Blume (1992) Insight and Industry: On the Dynamics of Technological Change in Medicine	1895–1990	Diagnostic Medical Imaging Community Evolution *NMR Evolution*
Kevles (1997) Naked to the Bone: Medical Imaging in the Twentieth Century	1895–1995	Diagnostic Medical Imaging Community Evolution *NMR Evolution*
Mitchell (1988) The diagnostic imaging industry: 1896-1988	1896–1988	Diagnostic Medical Imaging Community Evolution *NMR Evolution*
Wolbarst (1999) Looking Within: How X-Ray, CT, MRI, Ultrasound and other medical images are created and how they help physicians save lives	1895–1998	Diagnostic Medical Imaging Community Evolution *NMR Evolution*
Radiology (Journal of RSNA)	1923–1988	Diagnostic Medical Imaging Community Evolution *NMR Evolution*
Mattson & Simon (1996) The Pioneers of NMR and Magnetic Resonance in Medicine: The Story of MRI	1895–1995	*NMR Evolution*
Kleinfield (1985) A machine called Indomitable	1955–1983	*NMR Evolution*
Grant & Harris (1996) Encyclopedia of NMR: Volume 1: Historical Perspectives	1945–1995	*NMR Evolution*
Magnetic Resonance Imaging (Journal of the Society for Magnetic Resonance Imaging)	1982–1988	*NMR Evolution*
Mallard (2006) Magnetic Resonance Imaging-the Aberdeen perspective on developments in the early years	1960–1988	*NMR Evolution*
Tansey, Christie & Reynolds (1998) Making the human body transparent: The impact of NMR and MRI (Volume 2-Welcome Witness to 20th Century Medicine)	1955–1988	*NMR Evolution*
Joyce (2001) The transparent body: MRI, knowledge and practice	1955–2000	*NMR Evolution*
Diagnostic Imaging (Journal)	1981–1995	NMR Evolution **ACR Response**
Linton (1997) The American College of Radiology: The First 75 years	1895–1992	**ACR Response**
ACR Archive-Various Documents (central role of ACR Bulletin)	1960–1995	**ACR Response**

NOTE: Different shades of gray differentiate sources informing a unique process under study of other sources providing information on multiple co-evolving processes

Table 4: Typical Set of Incidents as Recorded in Sequence File (Phase II: External (C=2), NMR (C=3), and Internal (C=1) Gro



C	#	TimeL	PDate	Actor 1	Actor 2	Source	Detail	Page	Article Title	Incident's Description
2	3	Oct-79	Dec-79	ACR	FTC	ACR Bulletin	35(12)	3	Memo to the Membership	Chairman comment onf NYT article (Oct 7,1979) titled "Chiropractors campaign to with approval by Health Care System" [...] This is a tragic epilogue to a legal legislative trend which has resulted in the LICENSURE of Chiropractors in every state, THE HARRASSMENT OF ORGANIZED MEDICINE BY FTC, and suits for restraint of trade by the chiropractors. Relman (editor of NEJoM) points out that there cannot be two standards, one for chiropractors and another for medicine, an IT IS UP TO THE CHIROPRACTOR TO DEMONSTRATE THAT THEIR THEORIES ARE SOUND BY DOING RESEARCH & PUBLISHING THEIR EVIDENCE. UNTIL THAT TIME IT IS THE RESPONSIBILITY OF ORGANIZED MEDICINE TO WARN THE PUBLIC THAT CHIROPRACTIC THEORY IS UNSOPPORTED BY SCIENTIFIC EVIDENCE.
3	6	Dec-79	Dec-79	ACR	NIH	ACR Bulletin	35(12)	10	Here's what ACR Commissions do for you (Cont)	"[...] Commission on Equipment and Facilities [...]:(7) The COMMITTEE ON EMERGENT IMAGING MODALITIES received a NEW MODALITY CALLED NUCLEAR MAGNETIC RESONANCE. THE COMMITTEE CONCLUSION WAS THAT TECHNIQUES CURRENTLY AVAILABLE IN THIS MODALITY DO NOT PROVIDE SUFFICIENT REFINED IMAGE TO SUPPORT A CONFERENCE AT THIS TIME. THE COMMITTEE DOES SUGGEST THAT THE COLLEGE OFFER SUPPORT TO THE RADIATION STUDY SECTION OF THE NATIONAL INSTITUTE OF HEALTH FOR THEIR CONFERENCE ON NUCLEAR MAGNETIC RESONANCE"
1	21	May-80	May-80	ACR	-	ACR Bulletin	36(5)	4	Memo to the Membership	Chairman gives a detailed assessment of income and expenses of **ACR to show that even when constraint of activities are being considered to balance the ACR budget, an increment of dues seems likely. He also notes the financial dependence that ACR has with the government (GRANTS & CONTRACTS). Also mentioned a meeting with the deputy assistant secretary for health affairs for the issue of shortage of radiologists in the Armed Forces**

Table 5: Temporal Sequence of Events-Phase II-by Type (Table)

	Number of Events				Frequency of Events		
	Internal	External	NMR	Total	Internal	External	NMR
1979	2	3	1	6	33%	50%	17%
1980	12	24	4	40	30%	60%	10%
1981	19	15	5	39	49%	38%	13%
1982	20	29	9	58	34%	50%	16%
1983	8	13	5	26	31%	50%	19%
1984	14	17	8	39	36%	44%	21%
1985	10	29	6	45	22%	64%	13%
1986	12	28	4	44	27%	64%	9%
1987	5	20	1	26	19%	77%	4%
1988	12	27	2	41	29%	66%	5%
Total	114	205	45	364	31%	56%	12%

Table 6: Recoding of Events—Retroductive Procedure, Step I: Internal Events

Main	Sub	Category	Definition
1 (ACR Internal)	**A**	NMR	Any article (or article's piece) detailing ACR's INTERNAL activities/changes related to ***NMR devices***
	B	Other Technologies	Any article (or article's piece) detailing ACR's INTERNAL changes or activities related to ***OTHER IMAGING devices*** (CT, ultrasound, PET, etc.)
	C	Mission & Identity Claims	Any article (or article's piece) detailing a change or activities related to the ***mission*** of ACR (i.e., the mission/purpose of an organization is commonly discussed only by senior leaders) or the ACR's ***organizational identity*** (i.e., what the organization is or should be)
	D	Bylaws	Any article (or article's piece) detailing a change or activities related to the ***bylaws*** of the ACR (bylaws are the written rules under which this type of organization operates)
	E	Structure	Any article (or article's piece) detailing a change or activities related to the ***formal structure*** of the ACR (i.e., changes in number or function of particular commissions, changes of names, number of officers assigned, etc.)
	F	Leadership Team	Any article (or article's piece) detailing a change or activities related to the ***Board of Chancellors*** (i.e., members, chair, etc.), ***president, executive director, ACR staff or commission chairs***
	G	Resources	Any article (or article's piece) detailing ACR's activities related to financial resources (i.e., dues, other income sources, etc.)
	H	Training	Any article (or article's piece) detailing a ACR's activities related to professional/members' training

Table 7: Recoding of Events—Retroductive Procedure, Step I: External Events

Main	Sub	Category	Definition
2 (ACR External)	**Z**	NMR	Any article (or article's piece) detailing ACR's EXTERNAL activities/changes (i.e., talks, meetings, alliances, discussions, other types of exchanges with other community members) related to ***NMR devices***
	Y	Other Technologies	Any article (or article's piece) detailing EXTERNAL activities (i.e., talks, meetings, alliances, discussions, other types of exchanges with other community members) related to ***OTHER IMAGING devices*** (CT, ultrasound, mammography, X-rays, PET, etc.)
	X	New Organizations or Research Teams	Any article (or article's piece) detailing ACR's EXTERNAL activities (i.e., talks, meetings, alliances, discussions, other types of exchanges with other community members) related to ***NEW producers of imaging technology*** (i.e., those producers who HAVE ENTERED THE INDUSTRY SINCE 1972) or technology development teams (i.e., NMR scientists)
	W	Governmental Agencies	Any article or article's piece detailing ACR's EXTERNAL activities (i.e., talks, meetings, discussions, other types of exchanges with other community members) related to ***Government Agencies*** (i.e., FDA, HCFA, BRH, etc)
	U	Industry Incumbent Organizations	Any article (or article's piece) detailing ACR's EXTERNAL activities (i.e., talks, meetings, other types of exchanges) with **producers of old imaging technology** (i.e., those producers who had been participating in the industry before 1972)
	T	Other Medical Professions	Any article or article's piece detailing ACR's EXTERNAL activities (i.e., talks, meetings, etc.) related to ***Other Medical Professions (i.e., TURF)***
	S	PR & Mass Media Mgmt	Any article or article's piece detailing ACR's EXTERNAL activities (i.e., talks, meetings, etc.) related to ***Mass Media Management*** (i.e., management of public perceptions of ACR or radiology in general, PR actions)
	R	Other Radiological Associations	Any article (or article's piece) detailing ACR's EXTERNAL activities (i.e., talks, meetings, alliances, discussions, other types of exchanges with other community members) related to **other professional radiological associations** (i.e., RSNA, etc.) or the role of ACR as voice of the radiological profession

ENDNOTES

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[1] Although central to organizational studies since its inception, in the last decade, scholarship focused on technology and organizations has not occupied the central role that it used to, at least, according two influential reviews of this literature (Zammuto *et al.*, 2007; Orlikowski and Scott, 2008).

[2] There is an even more current research stream arguing that the main problem with these previous conceptualizations is the artificial way of separating technology and humans as distinct entities in the first place. They argue that humans and technology have no inherent properties but acquire attributes and capabilities through their mutual ***interpenetration*** (see Orlikowski, W. J., & Scott, S. V. 2008. Sociomateriality: Challenging the separation of technology, work and organization. ***The Academy of Management Annals***, 2(1): 433-474. for a great review of this research stream). Given the difficulty of engaging deeply with an actual research subject going through a "technological discontinuity" (these are known only after they have occurred), I chose to rely on older conceptualizations of technology in this investigation, but the conclusions of this study allowed me to reconsider this issue as part of my conclusions (see chapter 6 for a more detailed discussion of this issue).

[3] As in many other contexts within organizational studies, the issue of the most suitable level of analysis for the artifact under study was a key issue for a long time (see Abernathy, W. J., & Utterback, J. M. 1978. Patterns of industrial innovation. ***Technology Review***, 80: 40-47. and Henderson, R. M., & Clark, K. B. 1990. Architectural innovation: The reconfiguration of existing product technologies and the failure of established firms. ***Administrative Science Quarterly***, 35: 9-30. for contrasting views). Considering that the focus of this investigation is organizations' responses to changes in artifacts as a whole (technologies), I chose to adhere to the most current conceptualization of this model, not paying special attention to specific parts of the whole artifact (the NMR scanner). Future research could avoid this simplification and try to untangle the more subtle changes in subsystems within the NMR devices

[4] This later contribution is arguably the most important one, given the focus of previous literature on efficiency and technical considerations as drivers of this evolutionary process.

[5] Complete reviews of the history and emergence of the core technologies within this community can be reviewed in Blume, S. S. 1992. ***Insight and Industry: On the dynamics of technological change in medicine***. Cambridge, MA: The MIT Press. or in Kevles, B. H. 1997. ***Naked to the bone: Medical imaging in the twentieth century***. New Brunswick, NJ: Rutgers University Press. If a focus on the operation and physical principles of the technologies is the main interest, Wolbarst, A. B. 1999. ***Looking within: How X-ray, CT, MRI, Ultrasound, and other medical imgaes are created and how they help physicians save lives***. Berkeley, CA: University of California Press. provides a comprehensive review. Finally, Mitchell, W. 1988. The diagnostic imaging industry: 1896-1988, ***Unpublished Report***. Ann Arbor, MI. presents an outstanding review focused on the evolution of the commercialization of these technologies and the ecological dynamics the manufacturers of these technologies faced.

[6] Medical tomography research started in the late 1950s, and its first widespread use was developed by EMI Ltd in the late 1960s and early 1970s (Mitchell, 1988), but it seems important to start discussing it within the context of nuclear medical equipment to introduce the concept of SPECT and PET. I decided to introduce these devices at this point to maintain coherence behind each of the devices developed within this technological community. However, the reader needs to realize that all these devices emerged from different scientific fields, developers, and at different points in time, making it difficult to present a simple explanation to those who lack familiarity with these machines.

[7] Although I consulted multiple sources for producing this subsection, I relied heavily on the work of Otha Linton, a key leadership figure within ACR. He was known within radiological circles as Mr. Radiology and capped his tenure of more than 40 years working within ACR with a book detailing the history of the organization since its inception to the late 1990s.

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[8] Even though I have acknowledged the financial support of FMC Technologies Inc and the Irwin and Ferber Fellowship Award, it seems only fair to reiterate the critical role they played in the successful accomplishment of this research project. Not only did they allow me to pay the required fees to collect the central dataset for this investigation, but they also allowed me to cover the peripheral expenses related to multiple trips to the History Factory (http://www.historyfactory.com/) facility in Chantilly, Virginia, and other libraries around the country to collect additional contextual information.

[9] For readers interested in a more in-depth look at the evolution of MRI devices, I would recommend reading Joyce, K. A. 2008. ***Magnetic Appeal: MRI and the Myth of transparency***. Ithaca, NY: Cornell University Press.