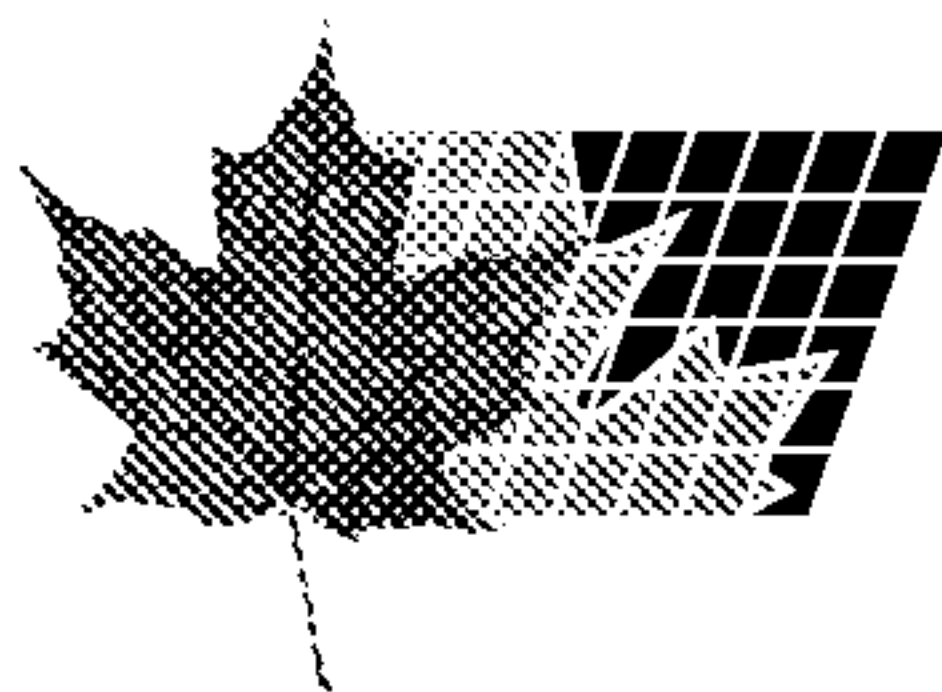




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(54) **KINASE INHIBITRICE DE NFB (I κ B), SOUS-UNITES DE LA
KINASE I κ B ET PROCEDES D'UTILISATION**
(54) **I κ B KINASE, SUBUNITS THEREOF, AND METHODS OF USING
SAME**

(57) La présente invention concerne des molécules d'acides nucléiques isolées, codant des polypeptides de la sous-unité catalytique de la kinase I κ B (IKK), qui sont associées à une protéine kinase sérine phosphorylant une protéine (I κ B) qui inhibe l'activité du facteur de transcription NF- κ B; des vecteurs contenant ces molécules d'acides nucléiques; et des cellules hôtes contenant ces vecteurs. En outre, l'invention concerne des séquences nucléotidiques qui peuvent se fixer sur une molécule d'acides nucléiques de l'invention, ces séquences nucléotidiques étant utilisées comme sondes ou comme molécules anti-sens. L'invention concerne également des sous-unités catalytiques isolées de l'IKK qui peuvent phosphoryler une protéine I κ B et des parties peptidiques de cette sous-unité de l'IKK. En outre, l'invention traite d'anticorps anti-IKK, qui se fixent de manière spécifique à un complexe de l'IKK ou à une sous-unité catalytique de l'IKK, ainsi que des fragments se fixant sur l'IKK de ces anticorps. L'invention concerne par ailleurs des procédés de purification sensible d'un complexe de l'IKK, des procédés d'identification d'un agent qui peut modifier l'association d'un complexe de l'IKK, ou d'une sous-unité catalytique de l'IKK, avec une seconde protéine, et des procédés d'identification de protéines qui peuvent interagir avec un complexe de l'IKK ou une sous-unité catalytique de l'IKK.

(57) The present invention provides an isolated nucleic acid molecule encoding I κ B kinase (IKK) catalytic subunit polypeptides, which are associated with an IKK serine protein kinase that phosphorylates a protein (I κ B) that inhibits the activity of the NF- κ B transcription factor, vectors comprising such nucleic acid molecules and host cells containing such vectors. In addition, the invention provides nucleotide sequences that can bind to a nucleic acid molecule of the invention, such nucleotide sequences being useful as probes or as antisense molecules. The invention also provides isolated IKK catalytic subunits, which can phosphorylate an I κ B protein, and peptide portions of such IKK subunit. In addition, the invention provides anti-IKK antibodies, which specifically bind to an IKK complex or an IKK catalytic subunit, and IKK-binding fragments of such antibodies. The invention further provides methods of substantially purifying an IKK complex, methods of identifying an agent that can alter the association of an IKK complex or an IKK catalytic subunit with a second protein, and methods of identifying proteins that can interact with an IKK complex or an IKK catalytic subunit.



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(54) Title: I κ B KINASE, SUBUNITS THEREOF, AND METHODS OF USING SAME (57) Abstract The present invention provides an isolated nucleic acid molecule encoding IκB kinase (IKK) catalytic subunit polypeptides, which are associated with an IKK serine protein kinase that phosphorylates a protein (IκB) that inhibits the activity of the NF-κB transcription factor, vectors comprising such nucleic acid molecules and host cells containing such vectors. In addition, the invention provides nucleotide sequences that can bind to a nucleic acid molecule of the invention, such nucleotide sequences being useful as probes or as antisense molecules. The invention also provides isolated IKK catalytic subunits, which can phosphorylate an IκB protein, and peptide portions of such IKK subunit. In addition, the invention provides anti-IKK antibodies, which specifically bind to an IKK complex or an IKK catalytic subunit, and IKK-binding fragments of such antibodies. The invention further provides methods of substantially purifying an IKK complex, methods of identifying an agent that can alter the association of an IKK complex or an IKK catalytic subunit with a second protein, and methods of identifying proteins that can interact with an IKK complex or an IKK catalytic subunit.		

I κ B KINASE, SUBUNITS THEREOF, AND METHODS OF USING SAME

This invention was made with government support under grant number CA50528 awarded by the National Institutes of Health. The government has certain rights
5 in the invention.

BACKGROUND OF THE INVENTION**FIELD OF THE INVENTION**

The present invention relates generally to molecular biology and biochemistry and more specifically
10 to a protein kinase, I κ B kinase, which is activated in response to environmental stresses and proinflammatory signals to phosphorylate inhibitors of the NF- κ B transcription factors and to methods of using the protein kinase.

15 **BACKGROUND INFORMATION**

The induction of gene expression due to exposure of a cell to a specific stimulus is a tightly controlled process. Depending on the inducing stimulus, it can be critical to survival of the cell that one or
20 more genes be rapidly induced, such that the expressed gene product can mediate its effect. For example, an inflammatory response stimulated due to an injury to or infection of a tissue results in rapid vasodilation in the area of the injury and infiltration of effector cells
25 such as macrophages. Vasodilation occurs within minutes of the response and is due, in part, to the expression of cytokines in the injured region.

The rapid induction, for example, of an inflammatory response or an immune response, requires
30 that the transcription factors involved in regulating

such responses be present in the cell in a form that is amenable to rapid activation. Thus, upon exposure to an inducing stimulus, the response can occur quickly. If, on the other hand, such transcription factors were not already present in a cell in an inactive state, the factors first would have to be synthesized upon exposure to an inducing stimulus, greatly reducing the speed with which a response such as an inflammatory response could occur.

10 Regulation of the activity of transcription factors involved in such rapid induction of gene expression can occur by various mechanisms. For example, in some cases, a transcription factor that exists in an inactive state in a cell can be activated by a post-
15 translational modification such as phosphorylation on one or more serine, threonine or tyrosine residues. In addition, a transcription factor can be inactive due to an association with a regulatory factor, which, upon exposure to an inducing stimulus, is released from the
20 transcription factor, thereby activating the transcription factor. Alternatively, an inactive transcription factor may have to associate with a second protein in order to have transcriptional activity.

 Rarely, as in the case of glucocorticoids, the
25 inducing stimulus interacts directly with the inactive transcription factor, rendering it active and resulting in the induction of gene expression. More often, however, an inducing stimulus initiates the induced response by interacting with a specific receptor present
30 on the cell membrane or by entering the cell and interacting with an intracellular protein. Furthermore, the signal generally is transmitted along a pathway, for example, from the cell membrane to the nucleus, due to a series of interactions of proteins. Such signal
35 transduction pathways allow for the rapid transmission of

an extracellular inducing stimulus such that the appropriate gene expression is rapidly induced.

Although the existence of signal transduction pathways has long been recognized and many of the cellular factors involved in such pathways have been described, the pathways responsible for the expression of many critical responses, including the inflammatory response and immune response, have not been completely defined. For example, it is recognized that various inducing stimuli such as bacteria or viruses activate common arms of the immune and inflammatory responses. However, differences in the gene products expressed also are observed, indicating that these stimuli share certain signal transduction pathways but also induce other pathways unique to the inducing stimulus. Furthermore, since inducing agents such as bacteria or viruses initially stimulate different signal transduction pathways, yet induce the expression of common genes, some signal transduction pathways must converge at a point such that the different pathways activate common transcription factors.

A clearer understanding of the proteins involved in such pathways can allow a description, for example, of the mechanism of action of a drug that is known to interfere with the expression of genes regulated by a particular pathway, but the target of which is not known. In addition, the understanding of such pathways can allow the identification of a defect in the pathway that is associated with a disease such as cancer. For example, the altered expression of cell adhesion molecules is associated with the ability of a cancer cell to metastasize. However, the critical proteins involved in the signal transduction pathway leading to expression of cell adhesion molecules have not been identified. Thus, a need exists to identify the proteins involved in

signal transduction pathways, particularly those proteins present at the convergence point of different initial pathways that result in the induction, for example, of gene products involved in the inflammatory and immune responses. The present invention satisfies this need and provides related advantages as well.

SUMMARY OF THE INVENTION

The present invention provides isolated nucleic acid molecules encoding full length human serine protein kinases, designated I κ B kinase (IKK) subunits IKK α and IKK β . The disclosed IKK subunits share substantial sequence homology and are activated in response to proinflammatory signals to phosphorylate proteins (I κ B's) that inhibit the activity of the NF- κ B transcription factor.

For example, the invention provides a nucleic acid molecule having the nucleotide sequence shown as SEQ ID NO: 1, which encodes a cytokine inducible I κ B kinase subunit designated IKK α , particularly the sequence shown as nucleotides -35 to 92 in SEQ ID NO: 1, and nucleic acid molecules encoding the amino acid sequence shown as SEQ ID NO: 2, as well as nucleotide sequences complementary thereto. In addition, the invention provides a nucleic acid molecule having the nucleotide sequence shown as SEQ ID NO: 14, which encodes a second cytokine inducible I κ B kinase subunit, designated IKK β , and nucleic acid molecules encoding the amino acid sequence shown as SEQ ID NO: 15, as well nucleotide sequences complementary thereto. The invention also provides vectors comprising the nucleic acid molecules of the invention and host cells containing such vectors.

In addition, the invention provides nucleotide sequences that bind to a nucleic acid molecule of the

invention, including to nucleotides -35 to 92 as shown in SEQ ID NO: 1. Such nucleotide sequences of the invention are useful as probes, which can be used to identify the presence of a nucleic acid molecule encoding an IKK subunit in a sample, and as antisense molecules, which can be used to inhibit the expression of a nucleic acid molecule encoding an IKK subunit.

The present invention also provides isolated full length human IKK subunits, which can phosphorylate an I κ B protein. For example, the invention provides an IKK α polypeptide having the amino acid sequence shown as SEQ ID NO: 2, particularly the amino acid sequence comprising amino acids 1 to 31 at the N-terminus of the polypeptide of SEQ ID NO: 2. In addition, the invention provides an IKK β polypeptide having the amino acid sequence shown as SEQ ID NO: 15. The invention also provides peptide portions of an IKK subunit, including, for example, peptide portions comprising one or more contiguous amino acids of the N-terminal amino acids shown as residues 1 to 31 in SEQ ID NO: 2. A peptide portion of an IKK subunit can comprise the kinase domain of the IKK subunit or can comprise a peptide useful for eliciting production of an antibody that specifically binds to an I κ B kinase or to the IKK subunit. Accordingly, the invention also provides anti-IKK antibodies that specifically bind to an IKK complex comprising an IKK subunit, particularly to the IKK subunit, for example, to an epitope comprising at least one of the amino acids shown as residues 1 to 31 of SEQ ID NO: 2, and also provides IKK subunit-binding fragments of such antibodies. In addition, the invention provides cell lines producing anti-IKK antibodies or IKK-binding fragments thereof.

The invention also provides isolated I κ B kinase complexes. As disclosed herein, an IKK complex can have

an apparent molecular mass of about 900 kDa or about 300 kDa. An IKK complex is characterized, in part, in that it comprises an IKK α subunit, an IKK β subunit, or both and can phosphorylate an I κ B protein.

5 The present invention further provides methods for isolating an IKK complex or an IKK subunit, as well as methods of identifying an agent that can alter the association of an IKK complex or an IKK subunit with a second protein that associates with the IKK *in vitro* or
10 *in vivo*. Such a second protein can be, for example, another IKK subunit; an I κ B protein, which is a substrate for IKK activity and is involved in a signal transduction pathway that results in the regulated expression of a gene; a protein that is upstream of the I κ B kinase in a
15 signal transduction pathway and regulates IKK activity; or a protein that acts as a regulatory subunit of the I κ B kinase or of an IKK subunit and is necessary for full activation of the IKK complex. An agent that alters the association of an IKK subunit with a second protein can
20 be, for example, a peptide, a polypeptide, a peptidomimetic or a small organic molecule. Such agents can be useful for modulating the level of phosphorylation of I κ B in a cell, thereby modulating the activity of NF- κ B in the cell and the expression of a gene regulated
25 by NF- κ B.

 The invention also provides methods of identifying proteins that can interact with an I κ B kinase, including with an IKK subunit, such proteins which can be a downstream effector of the IKK such as a
30 member of the I κ B family of proteins or an upstream activator or a regulatory subunit of an IKK. Such proteins that interact with an IKK complex or the IKK subunit can be isolated, for example, by coprecipitation with the IKK or by using the IKK subunit as a ligand, and
35 can be involved, for example, in tissue specific

regulation of NF- κ B activation and consequent tissue specific gene expression.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a nucleotide sequence (SEQ ID NO: 1; lower case letter) and deduced amino acid sequence (SEQ ID NO: 2; upper case letters) of full length human IKK α subunit of an IKK complex. Nucleotide positions are indicated to the right and left of the sequence; the "A" of the ATG encoding the initiator methionine is shown as position 1. Underlined amino acid residues indicate the peptide portions of the protein ("peptide 1" and "peptide 2") that were sequenced and used to design oligonucleotide probes. The asterisk indicates the sequence encoding the STOP codon.

Figure 2 shows a nucleotide sequence (SEQ ID NO: 14) encoding a full length IKK β polypeptide (see Figure 3). Numbers to the left and right of the sequence indicate nucleotide position number. The initiator ATG codon is present at nucleotides 36-38 and the first stop codon (TGA) is present at nucleotides 2304-2306.

Figure 3 shows an alignment of the deduced amino acid sequences of IKK α (" α ", SEQ ID NO: 2) and IKK β (" β ", SEQ ID NO: 15). Numbers to the right of the sequences indicate the respective amino acid positions. Underlined amino acid residues indicate peptide portions of the IKK β subunit that were sequenced and used to search an EST database (see Example III). Vertical bars between amino acid residues indicate identical amino acids; two dots between amino acid residues indicates very similar amino acids (e.g., Glu and Asp; Arg and Lys) and one dot between amino acid residues indicates a lesser degree of similarity. A dot within an amino acid sequence indicates a space introduced to maintain

sequence homology. The kinase domains in the N-terminal half of the sequences and helix-loop-helix domains in the C-terminal half of the sequences are bracketed and the leucine residues involved in the leucine zippers are indicated by the filled circles above the IKK α sequence.

DETAILED DESCRIPTION OF THE INVENTION

The present invention provides isolated nucleic acid molecules encoding polypeptide subunits of human serine protein kinase complex, the I κ B kinase (IKK), which is activated in response to proinflammatory signals and phosphorylates proteins (I κ B's) that bind to and inhibit the activity of NF- κ B transcription factors. For example, the invention provides an isolated nucleic acid molecule (SEQ ID NO: 1) encoding a full length human IKK α subunit having the amino acid sequence shown as SEQ ID NO: 2 (Figure 1). In addition, the invention provides an isolated nucleic acid molecule (SEQ ID NO: 14; Figure 2) encoding a full length human IKK β subunit having the amino acid sequence shown as SEQ ID NO: 15 (Figure 3).

As used herein, the term "isolated," when used in reference to a nucleic acid molecule of the invention, means that the nucleic acid molecule is relatively free from contaminating lipids, proteins, nucleic acids or other cellular material normally associated with a nucleic acid molecule in a cell. An isolated nucleic acid molecule of the invention can be obtained, for example, by chemical synthesis of the nucleotide sequence shown as SEQ ID NO: 1 or SEQ ID NO: 14 or by cloning the molecule using methods such as those disclosed in Examples II and III. In general, an isolated nucleic acid molecule comprises at least about 30% of a sample containing the nucleic acid molecule, and generally comprises about 50% or 70% or 90% of a sample, preferably 95% or 98% of the sample. Such an isolated nucleic acid

molecule can be identified by comparing, for example, a sample containing the isolated nucleic acid molecule with the material from which the sample originally was obtained. Thus, an isolated nucleic acid molecule can be identified, for example, by comparing the relative amount of the nucleic acid molecule in fraction of a cell lysate obtained following gel electrophoresis with the relative amount of the nucleic acid molecule in the cell, itself.

IKK α and IKK β have been designated IKK subunits because they are components of an approximately 900 kDa complex having I κ B kinase (IKK) activity and because they share substantial nucleotide and amino acid sequence homology. As disclosed herein, IKK α and IKK β are related members of a family of IKK catalytic subunits (see Figure 3). The 900 kDa I κ B kinase complex can be isolated in a single step, for example, by immunoprecipitation using an antibody specific for an IKK subunit or by using metal ion chelation chromatography methods (see Example IV). A 300 kDa IKK complex also can be isolated as disclosed herein and has kinase activity for an I κ B substrate (see Example III).

Nucleic acid molecules related to SEQ ID NO: 1 previously have been described (Connelly and Marcu, Cell. Mol. Biol. Res. 41:537-549 (1995), which is incorporated herein by reference). For example, Connelly and Marcu describe a 3466 base pair (bp) nucleic acid molecule (GenBank Accession #U12473; Locus MMU 12473), which is incorporated herein by reference), which encodes a full length mouse polypeptide having an apparent molecular mass of 85 kiloDaltons (kDa) and designated CHUK. A 2146 bp nucleic acid molecule (GenBank Accession #U22512; Locus HSU 22512), which is incorporated herein by reference), which encodes a portion of the polypeptide shown in SEQ ID NO: 2 also was described. However, the amino acid sequence deduced from #U22512 lacks amino

acids 1 to 31 as shown in SEQ ID NO: 2 and, therefore, is not a full length protein. In addition, several nucleotide differences occur in SEQ ID NO: 1 as compared to the sequence of #U22512, including nucleotide changes that encode different amino acids at positions 543, 604, 679, 680, 684 and 685 of SEQ ID NO: 2; silent nucleotide changes also occur at codons 665 and 678. The polypeptides encoded by the nucleotide sequences of GenBank Accession #U12473 and #U22512 share about 95% identity at the amino acid level and are substantially similar to that shown in SEQ ID NO: 2. No function has been demonstrated for the polypeptides described by Connelly and Marcu, although Regnier et al. (Cell 90:373-383 (1997)) recently have confirmed that human CHUK corresponds to IKK α , as disclosed herein.

A nucleic acid molecule of the invention is exemplified by the nucleotide sequences shown as SEQ ID NO: 1, which encodes a full length human IKK α (SEQ ID NO: 2; Figure 1), the activity of which is stimulated by a cytokine or other proinflammatory signal, and as SEQ ID NO: 14, which encodes a full length IKK β (SEQ ID NO: 15). Due to the degeneracy of the genetic code and in view of the disclosed amino acid sequence of a full length human IKK α (SEQ ID NO: 2) and of the IKK β (SEQ ID NO: 15), additional nucleic acid molecules of the invention would be well known to those skilled in the art. Such nucleic acid molecules, respectively, have a nucleotide sequence that is different from SEQ ID NO: 1 but, nevertheless, encodes the amino acid sequence shown as SEQ ID NO: 2, or have a nucleotide sequence that is different from SEQ ID NO: 14 but, nevertheless, encodes the amino acid sequence shown as SEQ ID NO: 15. Thus, the invention provides a nucleic acid molecule comprising a nucleotide sequence encoding the amino acid sequence of a full length human IKK α as shown in SEQ ID NO: 2 or of IKK β as shown in SEQ ID NO: 15.

As used herein, reference to "a nucleic acid molecule encoding an IKK subunit" indicates 1) the polynucleotide sequence of one strand of a double stranded DNA molecule comprising the nucleotide sequence
5 that codes for the IKK subunit and can be transcribed into an RNA that encodes the IKK subunit, or 2) an RNA molecule, which can be translated into an IKK subunit. It is recognized that a double stranded DNA molecule also comprises a second polynucleotide strand that is
10 complementary to the coding strand and that the disclosure of a polynucleotide sequence comprising a coding sequence necessarily discloses the complementary polynucleotide sequence. Accordingly, the invention provides polynucleotide sequences, including, for
15 example, polydeoxyribonucleotide or polyribonucleotide sequences that are complementary to the nucleotide sequence shown as SEQ ID NO: 1 or as SEQ ID NO: 14, or to a nucleic acid molecule encoding an IKK catalytic subunit having the amino acid sequence shown as SEQ ID NO: 2 or
20 as SEQ ID NO: 15, respectively.

As used herein, the term "polynucleotide" is used in its broadest sense to mean two or more nucleotides or nucleotide analogs linked by a covalent bond. The term "oligonucleotide" also is used herein to
25 mean two or more nucleotides or nucleotide analogs linked by a covalent bond, although those in the art will recognize that oligonucleotides generally are less than about fifty nucleotides in length and, therefore, are a subset within the broader meaning of the term
30 "polynucleotide."

In general, the nucleotides comprising a polynucleotide are naturally occurring deoxyribonucleotides, such as adenine, cytosine, guanine or thymine linked to 2'-deoxyribose, or ribonucleotides
35 such as adenine, cytosine, guanine or uracil linked to

ribose. However, a polynucleotide also can comprise nucleotide analogs, including non-naturally occurring synthetic nucleotides or modified naturally occurring nucleotides. Such nucleotide analogs are well known in the art and commercially available, as are polynucleotides containing such nucleotide analogs (Lin et al., Nucl. Acids Res. 22:5220-5234 (1994); Jellinek et al., Biochemistry 34:11363-11372 (1995); Pagratis et al., Nature Biotechnol. 15:68-73 (1997)). The covalent bond linking the nucleotides of a polynucleotide generally is a phosphodiester bond. However, the covalent bond also can be any of numerous other bonds, including a thiodiester bond, a phosphorothioate bond, a peptide-like bond or any other bond known to those in the art as useful for linking nucleotides to produce synthetic polynucleotides (see, for example, Tam et al., Nucl. Acids Res. 22:977-986 (1994); Ecker and Crooke, BioTechnology 13:351360 (1995)).

Where it is desired to synthesize a polynucleotide of the invention, the artisan will know that the selection of particular nucleotides or nucleotide analogs and the covalent bond used to link the nucleotides will depend, in part, on the purpose for which the polynucleotide is prepared. For example, where a polynucleotide will be exposed to an environment containing substantial nuclease activity, the artisan will select nucleotide analogs or covalent bonds that are relatively resistant to the nucleases. A polynucleotide comprising naturally occurring nucleotides and phosphodiester bonds can be chemically synthesized or can be produced using recombinant DNA methods, using an appropriate polynucleotide as a template. In comparison, a polynucleotide comprising nucleotide analogs or covalent bonds other than phosphodiester bonds generally will be chemically synthesized, although an enzyme such as T7 polymerase can incorporate certain types of

nucleotide analogs and, therefore, can be used to produce such a polynucleotide recombinantly from an appropriate template (Jellinek et al., *supra*, 1995).

The invention also provides nucleotide
5 sequences that can specifically hybridize to a nucleic acid molecule of the invention. Such hybridizing nucleotide sequences are useful, for example, as probes, which can hybridize to a nucleic acid molecule encoding an IKK catalytic subunit and allow the identification of
10 the nucleic acid molecule in a sample. A nucleotide sequence of the invention is characterized, in part, in that it is at least nine nucleotides in length, such sequences being particularly useful as primers for the polymerase chain reaction (PCR), and can be at least
15 fourteen nucleotides in length or, if desired, at least seventeen nucleotides in length, such nucleotide sequences being particularly useful as hybridization probes, although such sequences also can be used for PCR. A nucleotide sequence of the invention can comprise at
20 least six nucleotides 5' to nucleotide position 92 as shown in SEQ ID NO: 1 (Figure 1), preferably at least nine nucleotides 5' to position 92, or more as desired, where SEQ ID NO: 1 is shown in the conventional manner from the 5'-terminus (Figure 1; upper left) to the
25 3'-terminus. Such nucleotide sequences of the invention are particularly useful in methods of diagnosing a pathology, for example, a human disease, characterized by aberrant IKK activity. For convenience, such nucleotide sequences can comprise a kit, which can be made
30 commercially available and can provide a standardized diagnostic assay.

A nucleic acid molecule encoding an IKK α such as the nucleotide sequence shown in SEQ ID NO: 1 diverges from the sequence encoding the mouse homolog (GenBank
35 Accession #U12473) in the region encoding amino acid 30.

Thus, a nucleotide sequence comprising nucleotides 88 to 90 as shown in SEQ ID NO: 1, which encodes amino acid 30 of human IKK α , can be particularly useful, for example, for identifying the presence of a nucleic acid molecule
5 encoding a human IKK α in a sample. Furthermore, based on a comparison of SEQ ID NO: 1 with SEQ ID NO: 14, the skilled artisan readily can select nucleotide sequences that can hybridize with a nucleic acid molecule encoding a human IKK α or a human IKK β or both by designing the
10 sequence to contain conserved or non-conserved nucleotide sequences, as desired. For example, selection of a nucleotide sequence that is highly conserved among SEQ ID NO: 1 and SEQ ID NO: 14 can allow the identification of related members of the IKK subunit family of proteins.
15 In comparison, selection of a nucleotide sequence that is present, for example, in SEQ ID NO: 14, but that is not present in SEQ ID NO: 1 or that shares only minimal homology can allow identification of the expression of SEQ ID NO: 14 in a cell, irrespective of whether SEQ ID
20 NO: 1 also is expressed in the cell. It should be recognized, however, that a nucleotide sequence of the invention readily is identifiable in comparison to GenBank Accession #U12473 or #U22512 in that a nucleotide sequence of the invention is not the nucleotide sequence
25 of GenBank Accession #U12473 or #U22512.

A nucleotide sequence of the invention can comprise a portion of a coding sequence of a nucleic acid molecule encoding an IKK subunit or of a sequence complementary thereto, depending on the purpose for which
30 the nucleotide sequence is to be used. In addition, a mixture of a coding sequence and its complementary sequence can be prepared and, if desired, can be allowed to anneal to produce double stranded molecules.

The invention also provides antisense nucleic
35 acid molecules, which are complementary to a nucleic acid

molecule encoding an IKK subunit and can bind to and inhibit the expression of the nucleic acid molecule. As disclosed herein, expression of an antisense molecule complementary to the nucleotide sequence shown in SEQ ID NO: 1 inhibited the cytokine inducible expression of an NF- κ B dependent reporter gene in a cell (Example II.B.). Thus, an antisense molecule of the invention can be useful for decreasing IKK activity in a cell, thereby reducing or inhibiting the level of NF- κ B mediated gene expression. These experiments were performed twenty-four hours after the cells were transfected (Example II.B.). Expression of the antisense molecule in the cell also resulted in a decreased level of IKK α activity as compared to vector transfected control cells, indicating that the IKK α has a relatively short half life. Antisense nucleic acid molecules specific for IKK α or for IKK β or for both can be designed based on the criteria discussed above for the selection of hybridizing nucleotide sequences.

20 An antisense nucleic acid molecule of the invention can comprise a sequence complementary to the entire coding sequence of an IKK catalytic subunit such as a sequence complementary to SEQ ID NO: 1 or SEQ ID NO: 14, provided the antisense sequence is not complementary in its entirety to the sequences of GenBank Accession #U12473 or #U22512. In addition, a nucleotide sequence complementary to a portion of a nucleic acid molecule encoding an IKK subunit can be useful as an antisense molecule, particularly a nucleotide sequence
25 complementary to nucleotides -35 to 92 of SEQ ID NO: 1 or, for example, a nucleotide sequence comprising at least 9 nucleotides on each side of the ATG encoding the initiator methionine (complementary to positions -9 to 12 of SEQ ID NO: 1) or, if desired, at least 17 nucleotides
30 on each side of the ATG codon (complementary to positions
35

-17 to 20 of SEQ ID NO: 1), or to the corresponding sequences of SEQ ID NO: 14.

Antisense methods involve introducing the nucleic acid molecule, which is complementary to and can hybridize to the target nucleic acid molecule, into a cell. An antisense nucleic acid molecule can be a chemically synthesized polynucleotide, which can be introduced into the target cells by methods of transfection, or can be expressed from a plasmid or viral vector, which can be introduced into the cell and stably or transiently expressed using well known methods (see, for example, Sambrook et al., Molecular Cloning: A laboratory manual (Cold Spring Harbor Laboratory Press 1989); Ausubel et al., Current Protocols in Molecular Biology (Green Publ., NY 1989), each of which is incorporated herein by reference). One in the art would know that the ability of an antisense (or other hybridizing) nucleotide sequence to specifically hybridize to the target nucleic acid sequence depends, for example, on the degree of complementarity shared between the sequences, the GC content of the hybridizing molecules, and the length of the antisense nucleic acid sequence, which can be at least ten nucleotides in length, generally at least thirty nucleotides in length or at least fifty nucleotides in length, and can be up to the full length of a nucleotide sequence of SEQ ID NO: 1 or SEQ ID NO: 14 or a nucleotide sequence encoding an IKK subunit as shown in SEQ ID NO: 2 or in SEQ ID NO: 15 (see Sambrook et al., *supra*, 1989).

The invention also provides vectors comprising a nucleic acid molecule of the invention and host cells, which are appropriate for maintaining such vectors. Vectors, which can be cloning vectors or expression vectors, are well known in the art and commercially available. An expression vector comprising a nucleic

acid molecule of the invention, which can encode an IKK- α or can be an antisense molecule, can be used to express the nucleic acid molecule in a cell.

In general, an expression vector contains the
5 expression elements necessary to achieve, for example, sustained transcription of the nucleic acid molecule, although such elements also can be inherent to the nucleic acid molecule cloned into the vector. In particular, an expression vector contains or encodes a
10 promoter sequence, which can provide constitutive or, if desired, inducible expression of a cloned nucleic acid sequence, a poly-A recognition sequence, and a ribosome recognition site, and can contain other regulatory elements such as an enhancer, which can be tissue
15 specific. The vector also contains elements required for replication in a procaryotic or eukaryotic host system or both, as desired. Such vectors, which include plasmid vectors and viral vectors such as bacteriophage, baculovirus, retrovirus, lentivirus, adenovirus, vaccinia
20 virus, semliki forest virus and adeno-associated virus vectors, are well known and can be purchased from a commercial source (Promega, Madison WI; Stratagene, La Jolla CA; GIBCO/BRL, Gaithersburg MD) or can be constructed by one skilled in the art (see, for example,
25 Meth. Enzymol., Vol. 185, D.V. Goeddel, ed. (Academic Press, Inc., 1990); Jolly, Canc. Gene Ther. 1:51-64 (1994); Flotte, J. Bioenerg. Biomemb. 25:37-42 (1993); Kirshenbaum et al., J. Clin. Invest 92:381-387 (1993), which is incorporated herein by reference).

30 A nucleic acid molecule, including a vector, can be introduced into a cell by any of a variety of methods known in the art (Sambrook et al., *supra*, 1989, and in Ausubel et al., Current Protocols in Molecular Biology, John Wiley and Sons, Baltimore, MD (1994), which
35 is incorporated herein by reference). Such methods

include, for example, transfection, lipofection, microinjection, electroporation and infection with recombinant vectors or the use of liposomes.

Introduction of a nucleic acid molecule by
5 infection with a viral vector is particularly advantageous in that it can efficiently introduce the nucleic acid molecule into a cell *ex vivo* or *in vivo*. Moreover, viruses are very specialized and typically infect and propagate in specific cell types. Thus, their
10 natural specificity can be used to target the nucleic acid molecule contained in the vector to specific cell types. For example, a vector based on HIV-1 can be used to target an antisense IKK subunit molecule to HIV-1 infected cells, thereby reducing the phosphorylation of
15 I κ B, which can decrease the high level of constitutive NF- κ B activity present in HIV-1 infected cells. Viral or non-viral vectors also can be modified with specific receptors or ligands to alter target specificity through receptor mediated events.

20 A nucleic acid molecule also can be introduced into a cell using methods that do not require the initial introduction of the nucleic acid molecule into a vector. For example, a nucleic acid molecule encoding an IKK catalytic subunit can be introduced into a cell using a
25 cationic liposomes, which also can be modified with specific receptors or ligands as described above (Morishita et al., J. Clin. Invest., 91:2580-2585 (1993), which is incorporated herein by reference; see, also, Nabel et al., *supra*, 1993)). In addition, a nucleic acid
30 molecule can be introduced into a cell using, for example, adenovirus-polylysine DNA complexes (see, for example, Michael et al., J. Biol. Chem., 268:6866-6869 (1993), which is incorporated herein by reference). Other methods of introducing a nucleic acid molecule into
35 a cell such that the encoded IKK subunit or antisense

nucleic acid molecule can be expressed are well known (see, for example, Goeddel, *supra*, 1990).

Selectable marker genes encoding, for example, a polypeptide conferring neomycin resistance (Neo^R) also
5 are readily available and, when linked to a nucleic acid molecule of the invention or incorporated into a vector containing the nucleic acid molecule, allows for the selection of cells that have incorporated the nucleic acid molecule. Other selectable markers such as that
10 conferring hygromycin, puromycin or ZEOCIN (Invitrogen) resistance are known to those in the art of gene transfer can be used to identify cells containing the nucleic acid molecule, including the selectable marker gene.

A "suicide" gene also can be incorporated into
15 a vector so as to allow for selective inducible killing of a cell containing the gene. A gene such as the herpes simplex virus thymidine kinase gene (TK) can be used as a suicide gene to provide for inducible destruction of such cells. For example, where it is desired to terminate the
20 expression of an introduced nucleic acid molecule encoding IKK or an antisense IKK subunit molecule in cells containing the nucleic acid molecule, the cells can be exposed to a drug such as acyclovir or gancyclovir, which can be administered to an individual.

25 Numerous methods are available for transferring nucleic acid molecules into cultured cells, including the methods described above. In addition, a useful method can be similar to that employed in previous human gene transfer studies, where tumor infiltrating lymphocytes
30 (TILs) were modified by retroviral gene transduction and administered to cancer patients (Rosenberg et al., New Engl. J. Med. 323:570-578 (1990)). In that Phase I safety study of retroviral mediated gene transfer, TILs were genetically modified to express the Neomycin

resistance (Neo^R) gene. Following intravenous infusion, polymerase chain reaction analyses consistently found genetically modified cells in the circulation for as long as two months after administration. No infectious
5 retroviruses were identified in these patients and no side effects due to gene transfer were noted in any patients. These retroviral vectors have been altered to prevent viral replication by the deletion of viral gag, pol and env genes. Such a method can also be used ex
10 vivo to transduce cells taken from a subject (see Anderson et al., U.S. Patent No. 5,399,346, issued March 21, 1995, which is incorporated herein by reference).

When retroviruses are used for gene transfer,
15 replication competent retroviruses theoretically can develop due to recombination of retroviral vector and viral gene sequences in the packaging cell line utilized to produce the retroviral vector. Packaging cell lines in which the production of replication competent virus by
20 recombination has been reduced or eliminated can be used to minimize the likelihood that a replication competent retrovirus will be produced. Hence, all retroviral vector supernatants used to infect cells will be screened for replication competent virus by standard assays such
25 as PCR and reverse transcriptase assays.

To function properly, a cell requires the precise regulation of expression of nearly all genes. Such gene regulation is accomplished by activation or repression of transcription by various transcription
30 factors, which interact directly with regulatory sequences on nuclear DNA. The ability of transcription factors to bind DNA or activate or repress transcription is regulated in response to external stimuli. In the case of the transcription factor NF- κ B, critical factors
35 involved in the signaling pathway mediating its

activation have not been identified (Verma, et al., Genes Devel. 9:2723-2735 (1995); Baeuerle and Baltimore, Cell 87:13-20 (1996)).

NF- κ B is a member of the Rel family of
5 transcription factors, which are present in most if not
all animal cells (Thanos and Maniatis, Cell 80:629-532
(1995)). Rel proteins, which include, for example, RelA
(p65), c-Rel, p50, p52 and the *Drosophila* dorsal and Dif
gene products, are characterized by region of about 300
10 amino acids sharing approximately 35% to 61% homology
("Rel homology domain"). The Rel homology domain
includes DNA binding and dimerization domains and a
nuclear localization signal. Rel proteins are grouped
into one of two classes, depending on whether the protein
15 also contains a transcriptional activation domain
(Siebenlist et al., Ann. Rev. Cell Biol. 10:405-455
(1994)).

Rel proteins can form homodimers or
heterodimers, which can be transcriptionally activating
20 depending on the presence of a transactivation domain.
The most common Rel/NF- κ B dimer, which is designated
"NF- κ B," is a p50/p65 heterodimer that can activate
transcription of genes containing the appropriate κ B
binding sites. p50/p65 NF- κ B is present in most cell
25 types and is considered the prototype of the Rel/NF- κ B
family of transcription factors. Different dimers vary
in their binding to different κ B elements, kinetics of
nuclear translocation and levels of expression in a
tissue (Siebenlist et al., *supra*, 1994). As used herein,
30 the term "Rel/NF- κ B" is used to refer generally to the
Rel family of transcription factors, and the term "NF- κ B"
is used to refer specifically to the Rel/NF- κ B factor
consisting of a p50/p65 heterodimer.

NF- κ B originally was identified by its ability to bind a specific DNA sequence present in the immunoglobulin κ light chain gene enhancer, the " κ B element" (Sen and Baltimore, Cell 46:705-709 (1986)).

5 The κ B element has been identified in numerous cellular and viral promoters, including promoters present in human immunodeficiency virus-1 (HIV-1); immunoglobulin superfamily genes such as the MHC class 1 (H-2 κ) gene; cytokine genes such as the tumor necrosis factor α (TNF α), interleukin-1 β (IL-1 β), IL-2, IL-6 and the
10 granulocyte-macrophage colony stimulating factor (GM-CSF) gene; chemokine genes such as RANTES and IL-8; and cell adhesion protein genes such as E-selectin. The κ B element exhibits dyad symmetry and each half site of the
15 element likely is bound by one subunit of an NF- κ B dimer.

In the absence of an appropriate signaling stimulus, a Rel/NF- κ B is maintained in the cytoplasm in an inactive form complexed with an I κ B protein. Rel/NF- κ B transcriptional activity is induced by numerous
20 pathogenic events or stresses, including cytokines, chemokines, viruses and viral products, double stranded RNA, bacteria and bacterial products such as lipopolysaccharide (LPS) and toxic shock syndrome toxin-1, mitogens such as phorbol esters, physical and
25 oxidative stresses, and chemical agents such as okadaic acid and cycloheximide (Thanos and Maniatis, *supra*, 1995; Siebenlist et al., *supra*, 1994). Significantly, the expression of genes encoding agents such as TNF α , IL-1, IL-6, interferon- β and various chemokines, which induce
30 NF- κ B activity, are, themselves, induced by NF- κ B, resulting in amplification of their signal by a positive, self-regulatory loop (Siebenlist et al., *supra*, 1994). Phorbol esters, which activate T cells, also activate NF- κ B and immunosuppressants such as cyclosporin A
35 inhibit activation of T cells through T cell receptor

mediated signals (Baldwin, Ann. Rev. Immunol. 14:649-681 (1996), which is incorporated herein by reference).

Regulation of specific genes by NF- κ B can require interaction of NF- κ B with one or more other DNA binding proteins. For example, expression of E-selectin requires an interaction of NF- κ B, the bZIP protein ATF-2 and HMG-I(Y), and expression of the IL-2 receptor α gene requires an interaction of NF- κ B, HMG-I(Y) and the ets-like protein, ELF-1 (Baldwin, *supra*, 1996).

The numerous agents that induce activation of NF- κ B likely act through various converging signal transduction pathways, including pathways involving activation of protein kinase C, Raf kinase and tyrosine kinases. The ability of antioxidants to inhibit NF- κ B activation by various inducing agents suggests that reactive oxygen species are a converging point of such pathways (Siebenlist et al., *supra*, 1994).

Upon activation by an appropriate inducing agent, a Rel/NF- κ B dimer is translocated into the nucleus, where it can activate gene transcription. The subcellular localization of a Rel/NF- κ B is controlled by specific inhibitory proteins ("inhibitors of Rel/NF- κ B" or "I κ B's"), which noncovalently bind the Rel/NF- κ B and mask its nuclear localization signal (NLS), thereby preventing nuclear uptake. Various I κ B's, including, for example, I κ B α , I κ B β , Bcl-3 and the *Drosophila* cactus gene product, have been identified (Baeuerle and Baltimore, *supra*, 1996). In addition, Rel precursor proteins, such as p105 and p100, which are precursors of p50 and p52, respectively, function as I κ B's (Siebenlist et al., *supra*, 1994). I κ B α and I κ B β are expressed in most cell types and generally bind p65- and c-Rel-containing Rel/NF- κ B dimers. Other I κ B's appear to be expressed in

a tissue specific manner (Thompson et al., Cell 80:573-582 (1995)).

I κ B proteins are characterized by the presence of 5 to 8 ankyrin repeat domains, each about 30 amino acids, and a C-terminal PEST domain. For example, I κ B α contains a 70 amino acid N-terminal domain, a 205 amino acid internal domain containing the ankyrin repeats, and a 42 amino acid C-terminal domain containing the PEST domain (Baldwin, *supra*, 1996). Although I κ B proteins interact through their ankyrin repeats with the Rel homology domain of Rel/NF- κ B dimers, binding of particular I κ B proteins with particular Rel/NF- κ B proteins appears to be relatively specific. For example, I κ B α and I κ B β associate primarily with RelA- and c-Rel-containing Rel/NF- κ B dimers, thereby blocking their nuclear localization signal. The binding of an I κ B to NF- κ B also interferes with the ability of NF- κ B to bind DNA. However, whereas I κ B α is phosphorylated following exposure of cells to tumor necrosis factor (TNF), IL-1, bacterial lipopolysaccharide (LPS) or phorbol esters, I κ B β is phosphorylated in certain cell types only in response to LPS or IL-1 (Baldwin, *supra*, 1996). However, in other cell types, I κ B β is phosphorylated in response to the same signals that induce I κ B α , although with slower kinetics than I κ B α (DiDonato et al., Mol. Cell. Biol. 16:1295-1304 (1996), which is incorporated herein by reference).

Formation of a complex between an I κ B protein and a Rel protein is due to an interaction of the ankyrin domains with a Rel homology domain (Baeuerle and Baltimore, *supra*, 1996). Upon exposure to an appropriate stimulus, the I κ B portion of the complex is rapidly degraded and the Rel/NF- κ B portion becomes free to translocate to the cell nucleus. Thus, activation of a Rel/NF- κ B does not require *de novo* protein synthesis and,

therefore, occurs extremely rapidly. Consequently, activation of gene expression due to a Rel/NF- κ B can be exceptionally rapid and provides an effective means to respond to an external stimulus. Such a rapid response
5 of Rel/NF- κ B transcription factors is particularly important since these factors are involved in the regulation of genes involved in the immune, inflammatory and acute phase responses, including responses to viral and bacterial infections and to various stresses.

10 Upon exposure of a cell to an appropriate inducing agent, I κ B α , for example, is phosphorylated at serine residue 32 (Ser-32) and Ser-36 (Haskill et al., Cell 65:1281-1289 (1991)). Phosphorylation of I κ B α triggers its rapid ubiquitination, which results in
15 proteasome-mediated degradation of the inhibitor and translocation of active NF- κ B to the nucleus (Brown et al., Science 267:1485-1488 (1995); Scherer et al., Proc. Natl. Acad. Sci., USA 92:11259-11263 (1995); DiDonato et al., *supra*, 1996; DiDonato et al., Mol. Cell. Biol.
20 15:1302-1311 (1995); Baldi et al., J. Biol. Chem. 271:376-379 (1996)). The same mechanism also accounts for I κ B β degradation (DiDonato et al., *supra*, 1996).

Rel/NF- κ B activation can be transient or persistent, depending on the inducing agent and the I κ B
25 that is phosphorylated. For example, exposure of a cell to particular cytokines induces I κ B α phosphorylation and degradation, resulting in NF- κ B activation, which induces the expression of various genes, including the gene encoding I κ B α . The newly expressed I κ B α then binds to
30 NF- κ B in the nucleus, resulting in its export to the cytoplasm and inactivation and, therefore, a transient NF- κ B mediated response. In comparison, bacterial LPS induces I κ B β phosphorylation, resulting in NF- κ B activation. However, the I κ B β gene is not induced by

NF- κ B and, as a result, activation of NF- κ B is more persistent (Thompson et al., *supra*, 1995).

A constitutively active multisubunit kinase of approximately 700 kDa phosphorylates I κ B α at Ser-32 and
5 Ser-36 and, in some cases, requires polyubiquitination for activity (Chen et al., Cell 84:853-862 (1996); Lee et al., Cell 88:213-222 (1997)). The mitogen-activated protein kinase/ERK kinase kinase-1 (MEKK1) phosphorylates several proteins that copurify with this complex and have
10 molecular weights of approximately 105 kDa, 64 kDa and 54 kDa; three other copurifying proteins having molecular weights of about 200 kDa, 180 kDa and 120 kDa are phosphorylated in the absence of MEKK1 (Lee et al., *supra*, 1997). However, a catalytically inactive MEKK1
15 mutant, which can block TNF α mediated activation of the jun kinase, does not block NF- κ B activation (Liu et al., Cell 87:565-576 (1996)).

Overexpression of MEKK1 also induces the site-specific phosphorylation of I κ B α *in vivo* and can directly
20 activate I κ B α *in vitro* by an ubiquitin-independent mechanism. However, MEKK1 did not phosphorylate I κ B α at Ser-32 and Ser-36 in the *in vitro* experiments, indicating that it is not an I κ B α kinase, but may act upstream of I κ B α kinase in a signal transduction pathway (Lee et al.,
25 *supra*, 1997).

In addition to the above described ubiquitin dependent kinase 700 kDa complex, an ubiquitin independent 700 kDa complex, as well as an ubiquitin independent 300 kDa kinase complex phosphorylates I κ B α
30 Ser-32 and Ser-36, but not a mutant containing threonines substituted for these serines (Baeuerle and Baltimore, *supra*, 1996). The specific polypeptides responsible for the I κ B kinase activity of these complexes have not been described.

A double stranded RNA-dependent protein kinase (PKR) that phosphorylates I κ B α *in vitro* has been described (Kumar et al., Proc. Natl. Acad. Sci., USA 91:6288-6292 (1994)). Moreover, an antisense PKR DNA molecule prevented NF- κ B activation by double stranded RNA, but did not prevent NF- κ B activation by TNF α (Maran et al., Science 265:789-792 (1995)). Casein kinase II (CKII) also can interact with and phosphorylate I κ B α , although weakly as compared to CKII phosphorylation of casein, and the Ser-32 and Ser-36 residues in I κ B α represent CKII phosphorylation sites (Roulston et al., *supra*, 1995). However, all of the inducers of NF- κ B activity do not stimulate these protein kinases to phosphorylate I κ B, indicating that, if they are involved in NF- κ B activation, these kinases, like MEKK1, operate upstream of the I κ B kinase. Thus, a rapidly stimulated I κ B kinase that directly phosphorylates I κ B α on Ser-32 and Ser-36 and results in activation of NF- κ B has not been identified.

A putative serine-threonine protein kinase has been identified in mouse cells by probing for nucleic acid molecules that encode proteins containing a consensus helix-loop-helix domain, which is involved in protein-protein interactions (Connelly and Marcu, *supra*, 1995). This putative kinase, which is ubiquitously expressed in various established cell lines, but differentially expressed in normal mouse tissues, was named CHUK (conserved helix-loop-helix ubiquitous kinase; GenBank Accession #U12473). In addition, a nucleic acid molecule (GenBank Accession #U22512) encoding a portion of a human CHUK protein that is 93% identical at the nucleotide level (95% identical at the amino acid level) with the mouse CHUK also was identified. However, neither the function of a CHUK protein in a cell nor a potential substrate for the putative kinase was described.

The present invention provides an isolated I κ B kinase (IKK), including isolated full length IKK catalytic subunits. For example, the invention provides an isolated 300 kDa or 900 kDa complex, which comprises
5 an IKK α or an IKK β subunit and has I κ B kinase activity (see Examples I, III and IV). In addition, the invention provides is an isolated human IKK α catalytic subunit (SEQ ID NO: 2; Example II), which contains a previously undescribed N-terminal amino acid sequence and
10 essentially the C-terminal region of human CHUK (Connelly and Marcu, *supra*, 1995) and phosphorylates I κ B α on Ser-32 and Ser-36 and I κ B β on Ser-19 and Ser-23 (DiDonato et al., *supra*, 1996; see, also, Regnier et al., *supra*, 1997). The invention also provides an isolated IKK β
15 catalytic subunit (SEQ ID NO: 15; Example III), which shares greater than 50% amino acid sequence identity with IKK α , including conserved homology in the kinase domain, helix-loop-helix domain and leucine zipper domain.

As used herein, the term "isolated," when used
20 in reference to an I κ B kinase complex or to an IKK catalytic subunit of the invention, means that the complex or the subunit is relatively free from contaminating lipids, proteins, nucleic acids or other cellular material normally associated with an IKK in a
25 cell. An isolated 900 kDa I κ B kinase complex or 300 kDa complex can be isolated, for example, by immunoprecipitation using an antibody that binds to an IKK catalytic subunit (see Examples III and IV). In addition, an isolated IKK subunit can be obtained, for
30 example, by expression of a recombinant nucleic acid molecule such as SEQ ID NO: 1 or SEQ ID NO: 14, or can be isolated from a cell by a method comprising affinity chromatography using ATP or I κ B as ligands (Example I) or using an anti-IKK subunit antibody. An isolated IKK
35 complex or IKK subunit comprises at least 30% of the material in a sample, generally about 50% or 70% or 90%

of a sample, and preferably about 95% or 98% of a sample, as described above with respect to nucleic acids.

The amino acid sequences for MEKK1 (GenBank Accession # U48596; locus RNU48596), PKR (GenBank
5 Accession # M35663; locus HUMP68A) and CKII (GenBank Accession # M55268 J02924; locus HUMA1CKII) are different from the sequences of the IKK subunits disclosed herein (SEQ ID NO: 2 and SEQ ID NO: 15) and, therefore, are distinguishable from the present invention. In addition,
10 a full length human IKK α of the invention is distinguishable from the partial human CHUK polypeptide sequence in that the partial human CHUK polypeptide (Connelly and Marcu, *supra*, 1995; GenBank Accession #22512) lacks amino acids 1 to 31 as shown in SEQ ID
15 NO: 2. As disclosed herein, a polypeptide having the amino acid sequence of the partial human CHUK polypeptide does not have I κ B kinase activity when expressed in a cell, indicating that some or all of amino acid residues 1 to 31 are essential for kinase activity.

20 A full length IKK catalytic subunit of the invention is exemplified by human IKK α , which has an apparent molecular mass of about 85 kDa and phosphorylates I κ B α on Ser-32 and Ser-36. An IKK catalytic subunit of the invention also is exemplified by
25 IKK β , which is an 87 kDa polypeptide that shares substantial amino acid sequence homology with IKK α (Figure 3). As used herein, the term "full length," when used in reference to an IKK subunit of the invention, means a polypeptide having an amino acid sequence of an
30 IKK subunit expressed normally in a cell. Such a normally expressed IKK polypeptide begins with a methionine residue at its N-terminus (Met-1; Figure 3), the Met-1 being encoded by the initiator ATG (AUG) codon, and ends as a result of the termination of translation
35 due to the presence of a STOP codon. A full length human

IKK catalytic subunit can be a native IKK polypeptide, which is isolated from a cell, or can be produced using recombinant DNA methods such as by expressing the nucleic acid molecule shown as SEQ ID NO: 1 or SEQ ID NO: 14.

5 The apparent molecular mass of an isolated IKK subunit can be measured using routine methods such as polyacrylamide gel electrophoresis performed in the presence of sodium dodecyl sulfate (SDS-PAGE) or column chromatography performed under reducing and denaturing
10 conditions. In addition, the ability of an IKK subunit to phosphorylate I κ B α on Ser-32 and Ser-36 can be identified using the methods disclosed herein.

 With regard to the disclosed 85 kDa and 87 kDa apparent molecular masses of human IKK α and IKK β , it is
15 recognized that the apparent molecular mass of a previously unknown protein as determined, for example, by SDS-PAGE is an estimate based on the relative migration of the unknown protein as compared to the migration of several other proteins having known molecular masses.
20 Thus, one investigator reasonably can estimate, for example, that an unknown protein has an apparent molecular mass of 82 kDa, whereas a second investigator, looking at the same unknown protein under substantially similar conditions, reasonably can estimate that the
25 protein has an apparent molecular mass of 87 kDa. Accordingly, reference herein to an I κ B kinase having an apparent molecular mass of "about 85 kDa" indicates that the kinase migrates by SDS-PAGE in an 8% gel under reducing conditions in the range of 80 kDa to 90 kDa,
30 preferably in the range of 82 kDa to 87 kDa. Furthermore, reference herein to an 87 kDa IKK β indicates that IKK β has a relatively higher apparent molecular mass than the 85 kDa apparent molecular mass of IKK α .

An IKK catalytic subunit of the invention is exemplified by the isolated full length polypeptide comprising the amino acid sequence shown as SEQ ID NO: 2 or SEQ ID NO: 15. In addition, the invention provides peptide portions of an IKK subunit polypeptide, wherein such peptide portions contain at least three contiguous amino acids as shown in SEQ ID NO: 2 or SEQ ID NO: 15, and generally contain at least six contiguous amino acids or, if desired, at least nine contiguous amino acids, as provided herein. Thus, the invention provides peptide portions of IKK α , containing, for example, at least three contiguous amino acids of SEQ ID NO: 2, including amino acid residue 30, preferably at least four contiguous amino acids, including amino acid residue 30, and more preferably at least six contiguous amino acids, including amino acid residue 30. The invention also provides a peptide portion of IKK β comprising at least three contiguous amino acids, generally six contiguous amino acids, and preferably ten contiguous amino acids of SEQ ID NO: 15. It is recognized, however, that a peptide of the invention does not consist of a polypeptide disclosed as GenBank Accession #U12473 or #U22512.

A peptide portion of an IKK subunit generally is a tripeptide or larger, preferably a hexapeptide or larger, and more preferably a decapeptide or larger, up to a contiguous amino acid sequence having a maximum length that lacks one or more N-terminal or C-terminal amino acids of the full length polypeptide (SEQ ID NO: 2 or SEQ ID NO: 15). Thus, a peptide portion of IKK α having the amino acid sequence shown as SEQ ID NO: 2 can be from three amino acids long to 744 amino acids long, which is one residue less than the full length polypeptide, except as provided above.

A peptide portion of an IKK subunit polypeptide of the invention can be produced by any of several

methods well known in the art. For example, a peptide portion of an IKK subunit can be produced by enzymatic cleavage of an IKK subunit protein, which has been isolated from a cell, using a proteolytic enzyme such as trypsin, chymotrypsin, Lys-C or the like, or combinations of such enzymes. Such proteolytic cleavage products can be isolated using methods as disclosed in Example I, to obtain peptide portions of IKK α and IKK β , for example. A peptide portion of an IKK subunit also can be produced using methods of solution or solid phase peptide synthesis or can be expressed from a nucleic acid molecule such as a portion of the coding region of the nucleic acid sequence shown as SEQ ID NO: 1 or SEQ ID NO: 14, or can be purchased from a commercial source.

A peptide portion of an IKK subunit can comprise the kinase domain of the IKK subunit and, therefore, can have the ability to phosphorylate an I κ B protein. For example, a peptide portion of SEQ ID NO: 2 comprising amino acids 15 to 301 has the characteristics of a serine-threonine protein kinase domain (Hanks and Quinn, Meth. Enzymol. 200:38-62 (1991), which is incorporated herein by reference). Such a peptide portion of an IKK subunit can be examined for kinase activity by determining that it can phosphorylate I κ B α at Ser-32 and Ser-36 or I κ B β at Ser-19 and Ser-23, using methods as disclosed herein. In addition, a peptide portion of an IKK subunit can comprise an immunogenic amino acid sequence of the polypeptide and, therefore, can be useful for eliciting production of an antibody that can specifically bind the IKK subunit or to an IKK complex comprising the subunit, particularly to an epitope comprising amino acid residue 30 as shown in SEQ ID NO: 2 or to an epitope of SEQ ID NO: 15, provided said epitope is not present in a CHUK protein. Accordingly, the invention also provides anti-IKK antibodies, which specifically bind to an epitope of an IKK complex,

particularly an IKK catalytic subunit, and to IKK subunit binding fragments of such antibodies. In addition, the invention provides cell lines producing anti-IKK antibodies or IKK-binding fragments of such antibodies.

5 As used herein, the term "antibody" is used in its broadest sense to include polyclonal and monoclonal antibodies, as well as antigen binding fragments of such antibodies. With regard to an anti-IKK antibody of the invention, the term "antigen" means an IKK catalytic
10 subunit protein, polypeptide or peptide portion thereof, or an IKK complex comprising an IKK catalytic subunit protein, polypeptide or peptide portion thereof. Thus, it should be recognized that, while an anti-IKK antibody can bind to and, for example, immunoprecipitate an IKK
15 complex, the antibody specifically binds an epitope comprising at least a portion of an IKK catalytic subunit. An antibody of the invention also can be used to immunoprecipitate an IKK subunit, free of the IKK complex.

20 An anti-IKK antibody, or antigen binding fragment of such an antibody, is characterized by having specific binding activity for an epitope of an IKK subunit of at least about $1 \times 10^5 \text{ M}^{-1}$, generally, at least about $1 \times 10^6 \text{ M}^{-1}$. Thus, Fab, F(ab')₂, Fd and Fv fragments
25 of an anti-IKK antibody, which retain specific binding activity for an IKK subunit, are included within the definition of an antibody. In particular, an anti-IKK antibody can react with an epitope comprising the N-terminus of IKK α or with an epitope of IKK β , but not to
30 a polypeptide having an amino acid sequence shown as residues 32 to 745 of SEQ ID NO: 2.

The term "antibody" as used herein includes naturally occurring antibodies as well as non-naturally occurring antibodies, including, for example, single

chain antibodies, chimeric, bifunctional and humanized antibodies, as well as antigen-binding fragments thereof. Such non-naturally occurring antibodies can be constructed using solid phase peptide synthesis, can be produced recombinantly or can be obtained, for example, by screening combinatorial libraries consisting of variable heavy chains and variable light chains as described by Huse et al., Science 246:1275-1281 (1989), which is incorporated herein by reference. These and other methods of making, for example, chimeric, humanized, CDR-grafted, single chain, and bifunctional antibodies are well known to those skilled in the art (Winter and Harris, Immunol. Today 14:243-246 (1993); Ward et al., Nature 341:544-546 (1989) ; Harlow and Lane, Antibodies: A laboratory manual (Cold Spring Harbor Laboratory Press, 1988); Hilyard et al., Protein Engineering: A practical approach (IRL Press 1992); Borrabeck, Antibody Engineering, 2d ed. (Oxford University Press 1995); each of which is incorporated herein by reference).

An anti-IKK antibody of the invention can be raised using an isolated IKK subunit or a peptide portion thereof and can bind to a free, uncomplexed form of IKK subunit or can bind to IKK subunit when it is associated with a 300 kDa or 900 kDa IKK complex. In addition, an anti-IKK antibody of the invention can be raised against an isolated 300 kDa or 900 kDa I κ B kinase complex, which can be obtained as disclosed herein. For convenience, an antibody of the invention is referred to generally herein as an "anti-I κ B kinase antibody" or an "anti-IKK antibody." However, the skilled recognize that the various antibodies of the invention will have unique antigenic specificities, for example, for a free or complexed IKK subunit, or both, or for a 300 kDa or 900 kDa I κ B kinase complex, or both.

Anti-IKK antibodies can be raised using as an immunogen an isolated full length IKK catalytic subunit, which can be prepared from natural sources or produced recombinantly, or a peptide portion of an IKK subunit as defined herein, including synthetic peptides as described above. A non-immunogenic peptide portion of an IKK catalytic subunit can be made immunogenic by coupling the hapten to a carrier molecule such bovine serum albumin (BSA) or keyhole limpet hemocyanin (KLH), or by expressing the peptide portion as a fusion protein. Various other carrier molecules and methods for coupling a hapten to a carrier molecule are well known in the art and described, for example, by Harlow and Lane, *supra*, 1988). It is recognized that, due to the apparently high amino acid sequence identity of the full length human IKK α and mouse CHUK, the amino acid sequences of IKK α polypeptides, as well as IKK β polypeptides, likely are highly conserved among species, particularly among mammalian species. However, antibodies to highly conserved proteins have been raised successfully, for example, in chickens. Such a method can be used to obtain an antibody to an IKK subunit, if desired.

Particularly useful antibodies of the invention include antibodies that bind with the free, but not the complexed, form of an IKK subunit or, alternatively, with the complexed, but not free, form of an IKK subunit. Antibodies of the invention also include antibodies that bind with the 300 kDa I κ B kinase complex or the 900 kDa I κ B kinase complex or both. It should be recognized, however, that an antibody specific for the 300 kDa or 900 kDa I κ B kinase complex need not recognize an IKK subunit epitope in order to be encompassed within the claimed invention, since, prior to the present disclosure, the 300 kDa and 900 kDa IKK complexes were not known (see DiDonato et al., Nature 388:548-554 (1997)).

Antibodies of the invention that bind to an activated IKK but not to an inactive IKK, and, conversely, those that bind to an inactive form of the kinase but not to the activated form also are particularly useful. For example, an IKK can be activated by phosphorylation of an IKK subunit and, therefore, an antibody that recognizes the phosphorylated form of the IKK, but that does not bind to the unphosphorylated form can be obtained. In addition, IKK can be activated by release of a regulatory subunit and, therefore, an antibody that recognizes a form of the IKK complex that is not bound to the regulatory subunit can be obtained. Such antibodies are useful for identifying the presence of active IKK in a cell.

An anti-IKK antibody is useful, for example, for determining the presence or level of an IKK or of an IKK subunit in a tissue sample, which can be a lysate or a histological section. The identification of the presence or level of an IKK or an IKK subunit in the sample can be made using well known immunoassay and immunohistochemical methods (Harlow and Lane, *supra*, 1988). An anti-IKK antibody also can be used to substantially purify an I κ B kinase or an IKK subunit from a sample. In addition, an anti-IKK antibody can be used in a screening assay to identify agents that alter the activity of an I κ B kinase.

A kit incorporating an anti-IKK antibody, which can be specific for the active or inactive form of I κ B kinase or can bind to an IKK complex or to an IKK subunit, regardless of the activity state, can be particularly useful. Such a kit can contain, in addition to an anti-IKK antibody, a reaction cocktail that provides the proper conditions for performing the assay, control samples that contain known amounts of an IKK or IKK subunit and, if desired, a second antibody specific

for the anti-IKK antibody. Such an assay also should include a simple method for detecting the presence or amount of an IKK or an IKK subunit in a sample that is bound to the anti-IKK antibody.

5 A protein such as anti-IKK antibody, as well as an IKK subunit or a peptide portion thereof, can be labeled so as to be detectable using methods well known in the art (Hermanson, "Bioconjugate Techniques" (Academic Press 1996), which is incorporated herein by
10 reference; Harlow and Lane, 1988; chap. 9). For example, a protein can be labeled with various detectable moieties including a radiolabel, an enzyme, biotin or a fluorochrome. Reagents for labeling a protein such as an anti-IKK antibody can be included in a kit containing the
15 protein or can be purchased separately from a commercial source.

Following contact, for example, of a labeled antibody with a sample such as a tissue homogenate or a histological section of a tissue, specifically bound
20 labeled antibody can be identified by detecting the particular moiety. Alternatively, a labeled second antibody can be used to identify specific binding of an unlabeled anti-IKK antibody. A second antibody generally will be specific for the particular class of the first
25 antibody. For example, if an anti-IkB kinase antibody is of the IgG class, a second antibody will be an anti-IgG antibody. Such second antibodies are readily available from commercial sources. The second antibody can be labeled using a detectable moiety as described above.
30 When a sample is labeled using a second antibody, the sample is first contacted with a first antibody, which is an anti-IKK antibody, then the sample is contacted with the labeled second antibody, which specifically binds to the anti-IKK antibody and results in a labeled sample.

Methods for raising polyclonal antibodies, for example, in a rabbit, goat, mouse or other mammal, are well known in the art (see Example V). In addition, monoclonal antibodies can be obtained using methods that are well known and routine in the art (Harlow and Lane, *supra*, 1988). Essentially, spleen cells from a mouse immunized with an IKK complex or an IKK subunit or peptide portion thereof can be fused to an appropriate myeloma cell line such as SP/02 myeloma cells to produce hybridoma cells. Cloned hybridoma cell lines can be screened using a labeled IKK subunit to identify clones that secrete anti-IKK monoclonal antibodies. Hybridomas expressing anti-IKK monoclonal antibodies having a desirable specificity and affinity can be isolated and utilized as a continuous source of the antibodies, which are useful, for example, for preparing standardized kits as described above. Similarly, a recombinant phage that expresses, for example, a single chain anti-IKK also provides a monoclonal antibody that can be used for preparing standardized kits.

A monoclonal anti-IKK antibody can be used to prepare anti-idiotypic antibodies, which present an epitope that mimics the epitope recognized by the monoclonal antibody used to prepare the anti-idiotypic antibodies. Where the epitope to which the monoclonal antibody includes, for example, a portion of the IKK catalytic subunit kinase domain, the anti-idiotypic antibody can act as a competitor of I κ B and, therefore, can be useful for reducing the level of phosphorylation of I κ B and, consequently, the activity of NF- κ B.

The present invention further provides methods of identifying an agent that can alter the association of an IKK catalytic subunit with a second protein, which can be an upstream activator, a downstream effector such as I κ B, an interacting regulatory protein of the IKK

subunit, or an interacting subunit associated with the 300 kDa or 900 kDa I κ B kinase complex. As used herein, the term "associate" or "association," when used in reference to an IKK subunit and a second protein means
5 that the IKK subunit and the second protein have a binding affinity for each other such that they form a bound complex *in vivo* or *in vitro*, including in a cell in culture or in a reaction comprising substantially purified reagents. For convenience, the term "bind" or
10 "interact" is used interchangeably with the term "associate."

The affinity of binding of an IKK subunit and a second protein such as an I κ B or another IKK subunit or other subunit present in an IKK complex is characterized
15 in that it is sufficiently specific such that a bound complex can form *in vivo* in a cell or can form *in vitro* under appropriate conditions as disclosed herein. The formation or dissociation of a bound complex can be identified, for example, using the two hybrid assay or
20 demonstrating coimmunoprecipitation of the second protein with the IKK subunit, as disclosed herein, or using other well known methods such as equilibrium dialysis. Methods for distinguishing the specific association of an IKK subunit and a second protein from nonspecific binding to
25 the IKK subunit are known in the art and, generally, include performing the appropriate control experiments to demonstrate the absence of nonspecific protein binding.

As used herein, the term "second protein" refers to a protein that specifically associates with an
30 IKK subunit ("first protein"). Such a second protein is exemplified herein by I κ B proteins, including I κ B α and I κ B β , which are substrates for I κ B kinase activity and are downstream of the I κ B kinase in a signal transduction pathway that results in the regulated expression of a
35 gene. In addition, such second proteins are exemplified

by the proteins that, together with the IKK subunits, form a 300 kDa or 900 kDa I κ B kinase complex, which coimmunoprecipitates using an anti-IKK antibody (see Example IV). Furthermore, since IKK subunits such as
5 IKK α and IKK β interact with each other to form homodimers or heterodimers, a second protein also can be a second IKK subunit, which can be the same as or different from the "first" protein.

Agents that alter the association of an IKK
10 catalytic subunit and a second protein such as I κ B protein or an IKK regulatory subunit can be extremely valuable, for example, for limiting excessive cytokine expression as occurs in an acute phase response by preventing the activation of NF- κ B, thereby preventing
15 NF- κ B mediated induction of cytokine gene expression. Where, in a drug screening assay of the invention, the second protein is an I κ B, the IKK subunit can be any protein involved in I κ B kinase activity, including, for example, mouse CHUK (Connelly and Marcu, *supra*, 1995;
20 GenBank Accession #12473), which, prior to the present disclosure, was not known to have the ability to associate with I κ B or to have I κ B kinase activity.

In addition, a second protein can be a protein that is upstream of I κ B kinase in a signal transduction
25 pathway and associates with the IKK complex, particularly with an IKK catalytic subunit of the IKK complex. Such a second protein, which can be an upstream activator of the I κ B kinase, can be identified using routine methods for identifying protein-protein interactions as disclosed
30 herein. Such second proteins can be, for example, MEKK1 or PKR or CKII, each of which has been reported to be involved in a pathway leading to phosphorylation of I κ B and activation of NF- κ B, but neither of which has the characteristics expected of the common I κ B kinase present
35 at the point where the various NF- κ B activation pathways

converge (see, for example, Lee et al., *supra*, 1997), or can be the NF- κ B-inducing kinase (NIK), which reportedly is upstream from IKK in an NF- κ B activation pathway (Regnier et al., *supra*, 1997; Malinin et al., Nature 5 385:540-544 (1997)).

A second protein also can be a regulatory protein, which associates with an IKK catalytic subunit in an IKK complex, either constitutively as part of a 300 kDa or 900 kDa complex or in response to activation 10 of a pathway leading to IKK activation. Such a regulatory protein can inhibit or activate IKK activity depending, for example, on whether the regulatory protein is associated with IKK and whether the regulatory protein associates with an IKK catalytic subunit in a free form 15 or as part of an IKK complex. The regulatory protein also can be important for "docking" a catalytic IKK subunit to its substrate. The ability of a regulatory protein to associate with or dissociate from an IKK subunit or IKK complex can depend, for example, on the 20 relative phosphorylation state of the regulatory protein. It is recognized that an upstream activator of IKK also can interact with such a regulatory protein, thereby indirectly inhibiting or activating the IKK.

As disclosed herein, two copurifying proteins 25 were isolated by ATP and I κ B affinity chromatography and identified by SDS-PAGE (Example I). Partial amino acid sequences were determined and cDNA molecules encoding the proteins were obtained (see Examples I, II and III). One of the proteins has an apparent molecular mass of 85 kDa. 30 Expression in a cell of a cDNA molecule encoding the 85 kDa protein resulted in increased NF- κ B activity following cytokine induction as compared to control cells, whereas expression of the antisense of this cDNA decreased the basal NF- κ B activity in the cells and 35 prevented cytokine induction of NF- κ B activity.

Immunoprecipitation of the 85 kDa protein resulted in isolation of the IKK complex, the kinase activity of which was stimulated rapidly in response to TNF or to IL-1. Based on these functional analyses, the 85 kDa protein was determined to be a component of the 900 kDa I κ B kinase complex and has been designated IKK α (SEQ ID NO: 2). The second protein, which copurified with the 85 kDa I κ B kinase, has an apparent molecular mass of 87 kDa and shares greater than 50% amino acid sequence identity with IKK α and has been designated IKK β (SEQ ID NO: 15).

The ability of the 85 kDa and 87 kDa IKK subunits to associate with other proteins such as a regulatory subunit as well as with I κ B is suggested, for example, by the presence in the I κ B kinase of two different protein binding domains, a helix-loop-helix domain and a leucine zipper domain (see Connelly and Marcu, *supra*, 1995; see, also, Figure 3). While the leucine zipper motif mediates homotypic and heterotypic interactions between IKK α and IKK β , the helix-loop-helix motif serves as a binding site for regulatory proteins necessary for I κ B kinase activation.

A screening assay of the invention provides a means to identify an agent that alters the association of an IKK complex or an IKK catalytic subunit with a second protein such as the regulatory subunits discussed above. As used herein, the term "modulate" or "alter" when used in reference to the association of an IKK and a second protein, means that the affinity of the association is increased or decreased with respect to a steady state, control level of association, i.e., in the absence of an agent. Agents that can alter the association of an IKK with a second protein can be useful for modulating the level of phosphorylation of I κ B in a cell, which, in turn, modulates the activity of NF- κ B in the cell and the expression of a gene regulated by NF- κ B. Such an agent

can be, for example, an anti-idiotypic antibody as described above, which can inhibit the association of an IKK and I κ B. A peptide portion of I κ B α comprising amino acids 32 to 36, but containing substitutions for Ser-32
5 and Ser-36, is another example of such an agent, since the peptide can compete with I κ B α binding to IKK, as is the corresponding peptide of I κ B β .

A screening assay of the invention also is useful for identifying agents that directly alter the
10 activity of an IKK. While such an agent can act, for example, by altering the association of an IKK complex or IKK catalytic subunit with a second protein, the agent also can act directly as a specific activator or inhibitor of IKK activity. Specific protein
15 kinase inhibitors include, for example, staurosporin, the heat stable inhibitor of cAMP-dependent protein kinase, and the MLCK inhibitor, which are known in the art and commercially available. A library of molecules based, generally, on such inhibitors or on ATP or adenosine can
20 be screened using an assay of the invention to obtain agents that desirably modulate the activity of an IKK complex or an IKK subunit.

As disclosed herein, IKK activity can be measured by identifying phosphorylation, for example, of
25 I κ B α , either directly or using an antibody specific for the Ser-32 and Ser-36 phosphorylated form of I κ B α . An antibody that binds to I κ B α that is phosphorylated on Ser-32, for example, can be purchased from a commercial source (New England Biolabs; Beverly MA). Cultured cells
30 can be exposed to various agents suspected of having the ability to directly alter IKK activity, then aliquots of the cells either are collected or are treated with a proinflammatory stimulus such as a cytokine, and collected. The collected cells are lysed and the kinase
35 is immunoprecipitated using an anti-IKK antibody. A

substrate such as I κ B α or I κ B β is added to the immunocomplex and the ability of the IKK to phosphorylate the substrate is determined as described above. If desired, the anti-IKK antibody first can be coated onto a plastic surface such as in 96 well plates, then the cell lysate is added to the wells under conditions that allow binding of IKK by the antibody. Following washing of the wells, IKK activity is measured as described above. Such a method is extremely rapid and provides the additional advantage that it can be automated for high through-put assays.

A screening assay of the invention is particularly useful to identify, from among a diverse population of molecules, those agents that modulate the association of an IKK complex or an IKK catalytic subunit and another protein (referred to herein as a "second protein") or that directly alter the activity of IKK. Methods for producing libraries containing diverse populations of molecules, including chemical or biological molecules such as simple or complex organic molecules, peptides, proteins, peptidomimetics, glycoproteins, lipoproteins, polynucleotides, and the like, are well known in the art (Huse, U.S. Patent No. 5,264,563, issued November 23, 1993; Blondelle et al., Trends Anal. Chem. 14:83-92 (1995); York et al., Science 274:1520-1522 (1996); Gold et al., Proc. Natl. Acad. Sci., USA 94:59-64 (1997); Gold, U.S. Patent No. 5,270,163, issued December 14, 1993). Such libraries also can be obtained from commercial sources.

Since libraries of diverse molecules can contain as many as 10^{14} to 10^{15} different molecules, a screening assay of the invention provides a simple means for identifying those agents in the library that can modulate the association of an IKK and a second protein or can alter the activity of an IKK. In particular, a

screening assay of the invention can be automated, which allows for high through-put screening of randomly designed libraries of agents to identify those particular agents that can modulate the ability of an IKK and a
5 second protein to associate or that alter the activity of the IKK.

A drug screening assay of the invention utilizes an IKK complex, which can be isolated as disclosed herein; or an IKK subunit, which can be
10 expressed, for example, from a nucleic acid molecule encoding the amino acid sequence shown in SEQ ID NO: 2 or in SEQ ID NO: 15; or can be purified as disclosed herein; or can utilize an IKK subunit fusion protein such as an IKK α -glutathione-S-transferase (GST) or IKK β -histidine,
15 (HIS6) fusion protein, wherein the GST or HIS6 is linked to the IKK subunit and comprises a tag (see Example VI). The IKK or IKK subunit fusion protein is characterized, in part, by having an affinity for a solid substrate as well as having the ability to specifically associate with
20 an appropriate second protein such as an I κ B protein. For example, when an IKK catalytic subunit is used in a screening assay, the solid substrate can contain a covalently attached anti-IKK antibody, provided that the antibody binds the IKK subunit without interfering with
25 the ability of the IKK subunit to associate with the second protein. Where an IKK α -GST fusion protein, for example, is used in such a screening assay, the solid substrate can contain covalently attached glutathione, which is bound by the GST tag component of the fusion
30 protein. If desired, the IKK subunit or IKK subunit fusion protein can be part of an IKK complex in a drug screening assay of the invention.

A drug screening assay to identify an agent that alters the association of an IKK complex or an IKK
35 subunit and a second protein can be performed by

allowing, for example, the IKK complex or IKK subunit, which can be a fusion protein, to bind to the solid support, then adding the second protein, which can be an IkB such as IkB α , and an agent to be tested, under
5 conditions suitable for the association of the IKK and IkB α in the absence of a drug (see Example VI). As appropriate, the IKK can be activated or inactivated as disclosed herein and, typically, the IKK or the second protein is detectably labeled so as to facilitate
10 identification of the association. Control reactions, which contain or lack either, the IKK component, or the IkB protein, or the agent, or which substitute the IkB protein with a second protein that is known not to associate specifically with the IKK, also are performed.
15 Following incubation of the reaction mixture, the amount of IkB α specifically bound to the IKK in the presence of an agent can be determined and compared to the amount of binding in the absence of the agent so that agents that modulate the association can be identified.

20 An IKK subunit such as IKK α or IKK β used in a screening assay can be detectably labeled with a radionuclide, a fluorescent label, an enzyme, a peptide epitope or other such moiety, which facilitates a determination of the amount of association in a reaction.
25 By comparing the amount of specific binding of an IKK subunit or an IKK complex and IkB in the presence of an agent as compared to the control level of binding, an agent that increases or decreases the binding of the IKK and the IkB can be identified. In comparison, where a
30 drug screening assay is used to identify an agent that alters the activity of an IKK, the detectable label can be, for example, γ -³²P-ATP, and the amount of ³²P-IkB can be detected as a measure of IKK activity. Thus, the drug screening assay provides a rapid and simple method for
35 selecting agents that desirably alter the association of an IKK and a second protein such as an IkB or for

altering the activity of an IKK. Such agents can be useful, for example, for modulating the activity of NF- κ B in a cell and, therefore, can be useful as medicaments for the treatment of a pathology due, at least in part, to aberrant NF- κ B activity.

The method for performing a drug screening assay as disclosed herein also provides a research tool for identifying a target of a drug that is or can be used therapeutically to ameliorate an undesirable inflammatory or immune response, but for which the target of the drug is not known. Cytokine restraining agents, for example, are a class of agents that can alter the level of cytokine expression (U.S. Patent No. 5,420,109, issued May 30, 1995) and can be used to treat various pathologies, including patho-immunogenic diseases such as rheumatoid arthritis and those induced by exposure to bacterial endotoxin such as occur in septic shock (see, also, WO96/27386, published September 12, 1996).

The specific cellular target upon which a cytokine restraining agent acts has not been reported. However, the myriad of pathologic effects ameliorated by such agents are similar to various pathologies associated with aberrant NF- κ B activity, suggesting that cytokine restraining agents may target an effector molecule in a NF- κ B signal transduction pathway. Thus, one potential target of a cytokine restraining agent can be an I κ B kinase, particularly an IKK catalytic subunit of the kinase. Accordingly, a screening assay of the invention can be used to determine whether a cytokine restraining agent alters the activity of I κ B kinase or alters the association of an IKK and a second protein such as I κ B. If it is determined that a cytokine restraining agent has such an effect, the screening assay then can be used to screen a library of cytokine regulatory agents to

identify those having desirable characteristics, such as those having the highest affinity for the IKK.

The invention also provides a method of obtaining an isolated IKK complex or an IKK catalytic subunit. For example, a 300 kDa or a 900 kDa IKK complex, comprising an IKK α subunit can be isolated from a sample by immunoprecipitation using an anti-IKK α antibody or by tagging the IKK α and using an antibody specific for the tag (see Examples III and IV). In addition, an IKK catalytic subunit can be isolated from a sample by 1) incubating the sample containing the IKK subunit with ATP, which is immobilized on a matrix, under conditions suitable for binding of the IKK subunit to the ATP; 2) obtaining from the immobilized ATP a fraction of the sample containing the IKK subunit; 3) incubating the fraction containing the IKK subunit with an I κ B, which is immobilized on a matrix, under conditions suitable for binding of the IKK subunit to the I κ B; and 4) obtaining from the immobilized I κ B an isolated IKK catalytic subunit. Such a method of isolating an IKK subunit is exemplified herein by the use of ATP affinity chromatography and I κ B α affinity chromatography to isolate IKK α or IKK β from a sample of HeLa cells (see Example I).

The skilled artisan will recognize that a ligand such as ATP or an I κ B or an anti-IKK antibody also can be immobilized on various other matrices, including, for example, on magnetic beads, which provide a rapid and simple method of obtaining a fraction containing an ATP- or an I κ B-bound IKK complex or IKK subunit or an anti-I κ B kinase-bound IKK from the remainder of the sample. Methods for immobilizing a ligand such as ATP or an I κ B or an antibody are well known in the art (Haystead et al., Eur. J. Biochem. 214:459-467 (1993), which is incorporated herein by reference; see, also, Hermanson,

supra, 1996). Similarly, the artisan will recognize that a sample containing an IKK complex or an IKK subunit can be a cell, tissue or organ sample, which is obtained from an animal, including a mammal such as a human, and
5 prepared as a lysate; or can be a bacterial, insect, yeast or mammalian cell lysate, in which an IKK catalytic subunit is expressed from a recombinant nucleic acid molecule. As disclosed herein, a recombinantly expressed IKK α or IKK β such as a tagged IKK α or IKK β associates
10 into an active 300 kDa and 900 kDa IKK complex (see Examples III and IV).

The invention also provides a method of identifying a second protein that associates with an IKK complex, particularly with an IKK subunit. A
15 transcription activation assay such as the yeast two hybrid system is particularly useful for the identification of protein-protein interactions (Fields and Song, Nature 340:245-246 (1989), which is incorporated herein by reference). In addition, the two
20 hybrid assay is useful for the manipulation of protein-protein interaction and, therefore, also is useful in a screening assay to identify agents that modulate the specific interaction.

A transcription activation assay such as the
25 two hybrid assay also can be performed in mammalian cells (Fearon et al., Proc. Natl. Acad. Sci., USA 89:7958-7962 (1992), which is incorporated herein by reference). However, the yeast two hybrid system provides a particularly useful assay due to the ease of working with
30 yeast and the speed with which the assay can be performed. Thus, the invention also provides methods of identifying proteins that can interact with an IKK subunit, including proteins that can act as upstream activators or downstream effectors of IKK activity in a
35 signal transduction pathway mediated by the IKK or

proteins that bind to and regulate the activity of the IKK. Such proteins that interact with an IKK catalytic subunit can be involved, for example, in tissue specific regulation of NF- κ B activation or constitutive NF- κ B
5 activation and consequent gene expression.

The conceptual basis for a transcription activation assay is predicated on the modular nature of transcription factors, which consist of functionally separable DNA-binding and trans-activation domains. When
10 expressed as separate proteins, these two domains fail to mediate gene transcription. However, the ability to activate transcription can be restored if the DNA-binding domain and the trans-activation domain are bridged together through a protein-protein interaction. These
15 domains can be bridged, for example, by expressing the DNA-binding domain and trans-activation domain as fusion proteins (hybrids), where the proteins that are appended to these domains can interact with each other. The protein-protein interaction of the hybrids can bring the
20 DNA-binding and trans-activation domains together to create a transcriptionally competent complex.

One adaptation of the transcription activation assay, the yeast two hybrid system, uses *S. cerevisiae* as a host cell for vectors that express the hybrid proteins.
25 For example, a yeast host cell containing a reporter lacZ gene linked to a LexA operator sequence can be used to identify specific interactions between an IKK subunit and a second protein, where the DNA-binding domain is the LexA binding domain, which binds the LexA promoter, and
30 the trans-activation domain is the B42 acidic region. When the LexA domain is bridged to the B42 transactivation domain through the interaction of the IKK subunit with a second protein, which can be expressed, for example, from a cDNA library, transcription of the
35 reporter lacZ gene is activated. In this way, proteins

that interact with the IKK subunit can be identified and their role in a signal transduction pathway mediated by the IKK can be elucidated. Such second proteins can include additional subunits comprising the 300 kDa or
5 900 kDa IKK complex.

In addition to identifying proteins that were not previously known to interact with an IKK, particularly with an IKK α or IKK β subunit, a transcription activation assay such as the yeast two
10 hybrid system also is useful as a screening assay to identify agents that alter association of an IKK subunit and a second protein known to bind the IKK. Thus, as described above for *in vitro* screening assays, a transcription activation assay can be used to screen a
15 panel of agents to identify those agents particularly useful for altering the association of an IKK subunit and a second protein in a cell. Such agents can be identified by detecting an altered level of transcription of a reporter gene, as described above, as compared to
20 the level of transcription in the absence of the agent. For example, an agent that increases the interaction between an IKK subunit and I κ B can be identified by an increased level of transcription of the reporter gene as compared to the control level of transcription in the
25 absence of the agent. Such a method is particularly useful because it identifies an agent that alters the association of an IKK subunit and a second protein in a living cell.

In some cases, an agent may not be able to
30 cross the yeast cell wall and, therefore, cannot enter the yeast cell to alter a protein-protein interaction. The use of yeast spheroplasts, which are yeast cells that lack a cell wall, can circumvent this problem (Smith and Corcoran, In Current Protocols in Molecular Biology (ed.
35 Ausubel et al.; Green Publ., NY 1989), which is

incorporated herein by reference). In addition, an agent, upon entering a cell, may require "activation" by a cellular mechanism that may not be present in yeast. Activation of an agent can include, for example,
5 metabolic processing of the agent or a modification such as phosphorylation of the agent, which can be necessary to confer activity upon the agent. In this case, a mammalian cell line can be used to screen a panel of agents (Fearon et al., *supra*, 1992).

10 An agent that alters the catalytic activity of an IKK or that alters the association of an IKK subunit or IKK complex and a second protein such as an I κ B or an IKK regulatory subunit or an upstream activator of an IKK can be useful as a drug to reduce the severity of a
15 pathology characterized by aberrant NF- κ B activity. For example, a drug that increases the activity of an IKK or that increases the affinity of an IKK catalytic subunit and I κ B α can increase the amount of I κ B α phosphorylated on Ser-32 or Ser-36 and, therefore, increase the amount
20 of active NF- κ B and the expression of a gene regulated by NF- κ B, since the drug will increase the level of phosphorylated I κ B α in the cell, thereby allowing NF- κ B translocation to the nucleus. In contrast, a drug that decreases or inhibits the catalytic activity of an IKK or
25 the association of an IKK catalytic subunit and I κ B α can be useful where it is desirable to decrease the level of active NF- κ B in a cell and the expression of a gene induced by activated NF- κ B. It should be recognized that an antisense IKK subunit molecule of the invention also
30 can be used to decrease IKK activity in a cell by reducing or inhibiting expression of the IKK subunit or by reducing or inhibiting its responsiveness to an inducing agent such as TNF α , Il-1 or phorbol ester (see Example II). Accordingly, the invention also provides
35 methods of treating an individual suffering from a pathology characterized by aberrant NF- κ B activity by

administering to the individual an agent that modulates the catalytic activity of an IKK or that alters the association of an IKK subunit and a second protein such as I κ B or a subunit of a 300 kDa or 900 kDa IKK complex
5 that interacts with the IKK subunit.

An agent that decreases the activity of an IKK or otherwise decreases the amount of I κ B phosphorylation in a cell can reduce or inhibit NF- κ B mediated gene
10 expression, including, for example, the expression of proinflammatory molecules such as cytokines and other biological effectors involved in an inflammatory, immune or acute phase response. The ability to reduce or inhibit such gene expression can be particularly valuable
15 for treating various pathological conditions such as rheumatoid arthritis, asthma and septic shock, which are characterized or exacerbated by the expression of such proinflammatory molecules.

Glucocorticoids are potent anti-inflammatory
20 and immunosuppressive agents that are used clinically to treat various pathologic conditions, including autoimmune diseases such as rheumatoid arthritis, systemic lupus erythematosus and asthma. Glucocorticoids suppress the immune and inflammatory responses, at least in part, by
25 increasing the rate of I κ B α synthesis, resulting in increased cellular levels of I κ B α , which bind to and inactivate NF- κ B (Scheinman et al., Science 270:283-286 (1995); Auphan et al., Science 270:286-290 (1995)). Thus, glucocorticoids suppress NF- κ B mediated expression
30 of genes encoding, for example, cytokines, thereby suppressing the immune, inflammatory and acute phase responses. However, glucocorticoids and glucocorticoid-like steroids also are produced physiologically and are required for normal growth and development.
35 Unfortunately, prolonged treatment of an individual with higher than physiological amounts of glucocorticoids

produces clinically undesirable side effects. Thus, the use of an agent that alters the activity of an IKK or that alters the association of an IKK complex or IKK subunit and a second protein, as identified using a method of the invention, can provide a means for selectively altering NF- κ B activity without producing some of the undesirable side effects associated with glucocorticoid treatment.

Inappropriate regulation of Rel/NF- κ B transcription factors is associated with various human diseases. For example, many viruses, including human immunodeficiency virus-1 (HIV-1), herpes simplex virus-1 (HSV-1) and cytomegalovirus (CMV) contain genes regulated by a κ B regulatory element and these viruses, upon infecting a cell, utilize cellular Rel/NF- κ B transcription factors to mediate viral gene expression (Siebenlist et al., *supra*, 1994). Tat-mediated transcription from the HIV-1 enhancer, for example, is decreased if the NF- κ B and SP1 binding sites are deleted from the enhancer/promotor region, indicating that Tat interacts with NF- κ B, SP1 or other transcription factors bound at this site to stimulate transcription (Roulston et al., Microbiol. Rev. 59:481-505 (1995)). In addition, chronic HIV-1 infection, and progression to AIDS, is associated with the development of constitutive NF- κ B DNA binding activity in myeloid cells (Roulston et al., *supra*, 1995). Thus, a positive autoregulatory loop is formed, whereby HIV-1 infection results in constitutively active NF- κ B, which induces expression of HIV-1 genes (Baeuerle and Baltimore, Cell 87:13-20 (1996)). Constitutive NF- κ B activation also may protect cells against apoptosis, preventing clearance of virus-infected cells by the immune system (Liu et al., *supra*, 1996).

An agent that decreases the activity of an IKK or that alters the association of an IKK and a second

protein such that I κ B phosphorylation is decreased can be useful for reducing the severity of a viral infection such as HIV-1 infection in an individual by providing increased levels of unphosphorylated I κ B in virus-
5 infected cells. The unphosphorylated I κ B then can bind to NF- κ B in the cell, thereby preventing nuclear translocation of the NF- κ B and viral gene expression. In this way, the rate of expansion of the virus population can be limited, thereby providing a therapeutic advantage
10 to the individual.

In addition, the decreased level of NF- κ B activity may allow the virus-infected cell to undergo apoptosis, resulting in a decrease in the viral load in the individual. As such, it can be particularly useful
15 to treat virus-infected cells *ex vivo* with an agent identified using a method of the invention. For example, peripheral blood mononuclear cells (PBMCs) can be collected from an HIV-1 infected individual and treated in culture with an agent that decreases the activity of
20 an IKK or alters the association of an IKK complex or an IKK catalytic subunit with an I κ B. Such a treatment can be useful to purge the PBMCs of the virus-infected cells by allowing apoptosis to proceed. The purged population of PBMCs then can be expanded, if desired, and
25 readministered to the individual.

Rel/NF- κ B proteins also are involved in a number of different types of cancer. For example, the adhesion of cancer cells to endothelial cells is increased due to treatment of the cancer cells with IL-1,
30 suggesting that NF- κ B induced the expression of cell adhesion molecules, which mediated adherence of the tumor cells to the endothelial cells; agents such as aspirin, which decrease NF- κ B activity, blocked the adhesion by inhibiting expression of the cell adhesion molecules
35 (Tozawa et al., Cancer Res. 55:4162-4167 (1995)). These

results indicate that an agent that decreases the activity of an IKK or that decrease the association of an IKK and IκB or of an IKK subunit and a second protein, for example, a second protein present in an IKK complex, can be useful for reducing the likelihood of metastasis of a tumor in an individual.

As discussed above for virus-infected cells, constitutive NF-κB activation also may protect tumor cells against programmed cell death as well as apoptosis induced by chemotherapeutic agents (Liu et al., *supra*, 1996; Baeuerle and Baltimore, *Cell* 87:13-20 (1996)). Thus, an agent that decreases IKK activity or that decreases the association of IKK and IκB also can be useful for allowing programmed cell death to occur in a tumor cell by increasing the level of unphosphorylated IκB, which can bind NF-κB and decrease the level of active NF-κB in the tumor cell.

The following examples are intended to illustrate but not limit the present invention.

20

EXAMPLE I

IDENTIFICATION AND CHARACTERIZATION OF A HUMAN IκB KINASE COMPLEX AND IKK SUBUNITS

This example provides a method for identifying and isolating a cytokine responsive protein kinase complex that phosphorylates IκB, which regulates NF-κB activity, and catalytic subunits of the protein kinase complex.

A. Kinase assays:

Kinase assays were performed using GST fusion proteins containing amino acid residues 1 to 54 of IκB. The fusion proteins were linked to glutathione SEPHAROSE and the beads were used directly in the assays. At

earlier stages in the purification of the IKK activity, the beads were washed prior to loading onto the gel to minimize contributions from other proteins. In some of the later characterization of highly purified material, 5 soluble fusion protein was used.

Three distinct substrates for the IKK activity were used: 1) substrate "WT" contained amino acid residues 1 to 54 of I κ B α ; 2) substrate "AA" contained amino acid residues 1 to 54 of I κ B α , except that Ser-32 (S32) and S36 were replaced with Ala-32 (A32) and A36, 10 respectively; and 3) substrate "TT" contained amino acid residues 1 to 54 of I κ B α , except that S32 and S36 were replaced with Thr-32 (T32) and T36, respectively (DiDonato et al., Mol. Cell. Biol. 16:1295-1304 (1996)). 15 Each substrate was expressed as a GST fusion protein. The physiologic, inducible I κ B kinase is specific for S32 and S36 (WT) in I κ B α , but does not recognize the TT or AA mutants (DiDonato et al., Mol. Cell. Biol. 16:1295-1304 (1996)).

20 Kinase assays were carried out in 20 mM HEPES (pH 7.5-7.6), 20 mM β -glycerophosphate (β -GP), 10 mM MgCl₂, 10 mM PNPP, 100 μ M Na₃VO₄, 2 mM dithiothreitol (DTT), 20 μ M ATP, 10 μ g/ml aprotinin. NaCl concentration was 150-200 mM and the assays were carried out at 30°C 25 for 30 min. Fractionation was performed by SDS-PAGE, followed by quantitation by phosphoimager analysis.

B. Purification of IKK complex and IKK subunits:

The protein purification buffer (Buffer A) consisted of 20 mM Tris (pH 7.6, measured at RT), 20 mM 30 NaF, 20 mM β -GP, 1 mM PNPP, 500 μ M Na₃VO₄, 2 mM DTT, 2.5 mM metabisulfite, 5 mM benzamidine, 1 mM EDTA, 0.5 mM EGTA, 1 mM PMSF, and 10% glycerol. Brij-35 was added as indicated. Cell lysis buffer was Buffer A containing an

additional 19 mM PNPP, 20 mM β -GP and 500 μ M Na_3VO_4 , and 20 μ g/ml aprotinin, 2.5 μ g/ml leupeptin, 8.3 μ g/ml bestatin, 1.7 μ g/ml pepstatin.

Purification was performed using 5 to 130
5 liters of HeLa S3 cells. For illustration, the procedure for a 15 liter preparation is presented. All purification steps were performed in a cold room at 4°C.

In order to activate the IKK, cells were stimulated with $\text{TNF}\alpha$ prior to purification. $\text{TNF}\alpha$ was
10 either recombinant $\text{TNF}\alpha$, which was purchased from R&D Systems and used at 20 ng/ml, or HIS6-tagged $\text{TNF}\alpha$, which was expressed and partially purified from *E. coli* and used at 5 μ g/ml. $\text{TNF}\alpha$ -induced HeLa S3 cell killing activity assays were performed in the presence of
15 cycloheximide and indicated that the partially purified HIS6-tagged $\text{TNF}\alpha$ had approximately one-tenth the activity of the commercial $\text{TNF}\alpha$.

Fifteen liters of HeLa S3 cells were grown in suspension in high glucose Dulbecco's modified Eagle's
20 medium supplemented with 10% calf serum, 2 mg/ml L-glutamine, 100 U/ml penicillin/streptomycin, 0.11 mg/ml sodium pyruvate, and 1X nonessential amino acids (Irvine Scientific; Irvine CA). Cell density was approximately 5×10^5 cells/ml at the time of collection. Cells were
25 concentrated 10-fold by centrifugation. stimulated for 5 min with $\text{TNF}\alpha$ at 37°C, then diluted with 2.5 volumes of ice cold phosphate buffered saline (PBS) containing 50 mM NaF and pelleted at 2000 x g. The cell pellet was washed once with ice cold PBS/50 mM NaF, then suspended
30 in lysis buffer, quick frozen in liquid nitrogen and stored at -80°C.

For purification of I κ B kinase, cells were thawed and cytoplasmic extract prepared. Lysis was

achieved by 40 strokes in an all glass Dounce homogenizer (pestle A) in lysis buffer containing 0.05% NP-40 on ice. The homogenate was centrifuged at 12,000 rpm for 19 min in a Beckman SS34 rotor at 4°C.

5 Supernatant was collected and centrifuged at 38,000 rpm for 80 min in a Beckman 50.1 Ti rotor at 4°C. The supernatant (S100 fraction) was quick frozen in liquid nitrogen and stored at -80°C. Small aliquots of S100 material, prepared from either unstimulated HeLa
10 cells or from TNF α stimulated cells, were purified in a single passage over a SUPEROSE 6 gel filtration column (1.0 x 30 cm; Pharmacia; Uppsalla Sweden) equilibrated in Buffer A containing 0.1% Brij-35 and 300 mM NaCl and eluted at a flow rate of 0.3 ml/min. 0.6 ml fractions
15 were collected and kinase assays were performed on an aliquot of each fraction. The high molecular weight material (fractions 16-20) contained TNF α -inducible IKK activity, which is specific for the WT substrate.

110 ml of S100 material (900 mg of protein;
20 Bio-Rad Protein Assay) was pumped onto a Q-SEPHAROSE FAST FLOW column (56 ml bed volume, 2.6 cm ID) equilibrated at 2 ml/min with Buffer A containing 0.1% Brij-35. After the sample was loaded, the column was washed with 100 ml of Buffer A containing 0.1% Brij-35 and 100 mM NaCl, then
25 a linear NaCl gradient was run from 100-300 mM. The gradient volume was 500 ml and the flow rate was 2 ml/min. Ten ml fractions were collected and the kinase assay was performed on those fractions that eluted during the gradient. Fractions corresponding to the
30 TNF α -inducible IKK activity (fractions 30-42; i.e., 20-32 of the gradient portion) were pooled. The pooled material contained 40 mg of protein.

The pooled material was diluted to 390 ml by addition of Buffer A containing 0.1 % Brij-35 and loaded

onto a pre-equilibrated 5 ml HITRAP Q column (Pharmacia) at a flow rate of 4 ml/min. Following sample loading, the column was washed with 20 ml of Buffer A containing 0.1 % Brij-35. The protein was eluted at 1 ml/min
5 isocratically in Buffer A containing 0.1 % Brij-35 and 300 mM NaCl and 1 ml fractions were collected. Protein-containing fractions were identified using the BioRad assay and were collected and pooled to yield 4 ml of solution. Previously performed control experiments
10 demonstrated that the IKK activity directly correlated with protein concentration.

The pooled material was diluted 1:1 with ATP column buffer (20 mM HEPES (pH 7.3), 50 mM β -GP, 60 mM $MgCl_2$, 1 mM Na_2VO_4 , 1.5 mM EGTA, 1 mM DTT, 10 μ g/ml
15 aprotinin), then passed 4 times over a γ -ATP affinity column having 4 ml bed volume (Haystead et al., *supra*, 1993); the column had been prewashed with 2 M NaCl, 0.25% Brij-35 and equilibrated with 10 bed volumes of ATP column buffer containing 0.05% Brij-35 at a flow rate of
20 0.5 ml/min. Following loading of the sample, the column was washed with 10 ml of ATP column buffer containing 0.05% Brij-35, then with 10 ml ATP column buffer containing 0.05% Brij-35 and 250 mM NaCl.

Bound material was eluted in 10 ml of ATP
25 column buffer containing 0.05 % Brij-35, 250 mM NaCl and 10 mM ATP (elution buffer). Elution was performed by passing 5 ml of elution buffer through the column, allowing the column to incubate, capped, for 20 min, then passing an additional 5 ml of elution buffer through the
30 column. The samples were pooled to yield 10 ml.

The 10 ml pooled sample from the ATP column was diluted with 30 ml Buffer A containing 0.1 % Brij-35 and loaded onto a 1 ml HITRAP Q column (Pharmacia) at 1 ml/min. The column was eluted at 0.4 ml/min with

Buffer A containing 0.1 % Brij-35 and 300 mM NaCl. 0.2 ml fractions were collected and the four protein-containing fractions were pooled (0.5 mg). The pooled material was concentrated to 200 μ l on a 10K NANOSEP concentrator (Pall/Filtron) and loaded onto a SUPEROSE 6 gel filtration column (1.0 x 30 cm). The SUPEROSE 6 column was equilibrated in Buffer A containing 0.1 % Brij-35 and 300 mM NaCl and run at a flow rate of 0.3 ml/min; 0.6 ml fractions were collected. Fractions 17, 18 and 19 contained kinase activity.

Based on silver stained SDS-PAGE gels, the final purified material consisted of approximately 20 μ g to 40 μ g of total protein, of which approximately 2 μ g corresponded to the 85 kDa band, later designated IKK α (see Example II). A second band migrating at 87 kDa was later designated IKK β (see Example III). The total time from the thawing of the S100 material until the collection of fractions from the gel filtration column was 24 hours.

20 C. Confirmation of IKK purification:

Since the 85 kDa IKK α band identified by the kinase assay following the above procedure contained only about 10% of the total purified protein, three additional criteria were used to confirm that the identified band was an intrinsic component of the IKK complex.

In one procedure, the elution profile of the SUPEROSE 6 column was analyzed by silver stained 8% SDS-PAGE gels, then compared to the kinase activity profile. For this analysis, 0.3 ml fractions were collected from the SUPEROSE 6 column, then separated by 8% SDS-PAGE and silver stained. This comparison confirmed that a single band of 85 kDa correlated precisely with the elution of IKK activity.

In a second procedure, the IKK activity was further purified on a substrate affinity column at 4°C. A GST fusion protein was prepared containing the A32/A36 1 to 54 amino acid sequence of IκBα repeated 8 times (GST-(8X-AA)). The GST-(8X-AA) then was covalently linked to a CNBr activated SEPHAROSE 4B resin to produce the substrate affinity resin.

IKK-containing material was diluted into Buffer A to yield a final concentration of 70 mM NaCl, 0.025% Brij-35, then added to the substrate affinity resin at a ratio of 4:1 (solution:swollen beads). The resin was suspended and the mixture rotated gently overnight in a small column at 4°C. The resin was allowed to settle for 30 min, then the column was eluted by gravity. The column was washed with 4 bed volumes Buffer A containing 0.02% Brij-35, then the resin was suspended with 1.1 bed volumes of Buffer A containing 600 mM NaCl and 0.1 % Brij-35. The resin was allowed to settle for 40 min, then gravity elution was performed. The column was washed with an additional 1.1 bed volumes of Buffer A containing 600 mM NaCl and 0.1 % Brij-35 and the two fractions were pooled.

The IκBα substrate affinity column was used for two separate experiments. In one experiment, the material that eluted from the final SUPEROSE 6 column was further purified on the IκBα substrate affinity column. In the second experiment, material obtained after the initial Q-SEPHAROSE column was purified on the IκBα substrate affinity column. The Q-SEPHAROSE bound fraction then was further purified on the ATP column and the SUPEROSE 6 column (see above).

Analysis of the purified material from these two experiments by silver stained SDS-PAGE gels revealed different protein profiles. However, comparison of these

profiles revealed only two bands common to both preparations, one of which was confirmed to be the same 85 kDa IKK α band that was identified by the SUPEROSE 6 profile analysis and cofractionated with I κ B kinase activity. The other band, which was 87 kDa in size, later was identified as IKK β . In several different experiments, the 85 kDa protein and 87 kDa protein were specifically purified by the substrate affinity column in what appeared to be an equimolar ratio.

10 In a third procedure, purified IKK was treated with excess phosphatase, which inactivates the IKK, then reactivated by addition of a semi-purified HeLa extract. Phosphatase inactivation was performed by adding excess protein phosphatase 2A catalytic domain (PP2A) to
15 purified I κ B kinase in 50 mM Tris (pH 7.6), 50 mM NaCl, 1 mM MgCl₂, then equilibrating the reaction for 60 min at 30°C. 1.25 μ M okadaic acid was added to completely inactivate the phosphatase and the phosphatase inactivated material was used in standard kinase assays
20 and to perform the reactivation and phosphorylation procedure.

Cytoplasmic extract was prepared using HeLa S3 cells. The cells were stimulated with TNF α for 5 min, then harvested in lysis buffer containing 0.1 % NP-40 and
25 0.15 M NaCl. Reactivation was performed at 30°C in kinase buffer for 60 min in the absence of (γ -³²P)ATP. Samples containing only cold ATP were used for kinase activity assays. Reactivation by the HeLa cell extract was performed in the presence of (γ -³²P)ATP, then the
30 sample was separated by 8% SDS-PAGE and examined by autoradiography. A band of approximately 86 kDa was phosphorylated in the reactivated material and, associated with the reactivation procedure, was restoration of the IKK activity.

D. Partial amino acid sequences of IKK α and IKK β

Following SDS-PAGE as described above, the 85 kDa IKK α and 87 kDa IKK β bands were excised from the gel and submitted for internal peptide sequencing analysis. From the IKK α polypeptide, the sequences of two proteolytic fragments were identified, as follows: KIIDL $\overline{\text{LPK}}$ (SEQ ID NO: 3) and KHR(D/A)LKPENIVLQDVG(P/G)K (SEQ ID NO: 4). Where a residue could not be unambiguously determined, an "X" was used to indicate no amino acid could be determined and parentheses were used to delimit amino acids that could not be distinguished. Since Lys-C protease was used to digest the protein, the presence of lysine residues at the N-termini of the peptides was inferred. From the 87 kDa IKK β band, the sequences of five proteolytic fragments were determined (see Figure 3, underlined; see, also, Example III).

EXAMPLE IIIDENTIFICATION AND CHARACTERIZATION
OF A FULL LENGTH HUMAN IKK α SUBUNIT

This example provides methods for isolating a nucleic acid molecule encoding the IKK α subunit and for characterizing the functional activity of the subunit.

A. Cloning of cDNA encoding human IKK α :

Degenerate oligonucleotide (length) sequences of the amino acid sequences of two peptide fragments (SEQ ID NOS: 3 and 4) of the IKK α (see Figure 1) were searched in the GenBank DNA sequence database. This search revealed that nucleotide sequences encoding both peptide fragments were present in a partial cDNA encoding a portion of a protein designated human CHUK (GenBank Accession #U22512; Connelly and Marcu, *supra*, 1995).

Based on the human CHUK cDNA sequence, PCR primers were prepared corresponding to the 5'-terminus (5'-CCCCAT**ATG**TACCAGCATCGGGAA-3'; SEQ ID NO: 5) and 3'-terminus (3'-CCCCTCGAGTTCTGTTAACCAACT-5'; SEQ ID NO: 6). SEQ ID NO: 5 also contains a Nde I restriction endonuclease site (underlined) and an ATG (AUG) methionine codon (bold) and SEQ ID NO: 6 also contains an Xho I site. RNA was isolated from HeLa cells and first strand cDNA was prepared and used for a template by PCR using SEQ ID NOS: 5 and 6 as primers. The resulting 2.1 kilobase (kb) fragment was gel purified, ³²P-labeled using oligo-dT and random primers, and used to screen a human fetal brain library (Clontech; Palo Alto CA) under high stringency conditions (50% formamide, 42°C; Sambrook et al., supra, 1989).

In order to obtain the 5'-end of the cDNA encoding IKK α , positive plaques from above were screened by PCR using two internal primers, (5'-CATGGCACCATCGTTCTCTG-3'; SEQ ID NO: 7), which is complementary to the sequence including the Ban I site around position 136 of SEQ ID NO: 1, and (5'-CTCAAAGAGCTCTGGGGCCAGATAC-3'; SEQ ID NO: 8), which is complementary to the sequence including the Sac I site around position 475, and a vector specific primer (TCCGAGATCTGGACGAGC-3'; SEQ ID NO: 9), which is complementary to vector sequences at the 5'-end of the cDNA insert. The longest PCR product was selected and sequenced by the dideoxy method.

DNA sequencing revealed that the cloned IKK α cDNA contained an additional 31 amino acids at the N-terminus as compared to human CHUK. The human IKK α shares a high amount of sequence identity with a protein designated mouse CHUK (GenBank Accession #U12473; Connelly and Marcu, supra, 1995). Although the mouse CHUK contains a domain having characteristics of a

serine-threonine protein kinase, no functional activity of the protein was reported and no potential substrates were identified. The putative serine-threonine protein kinase domain of human CHUK was truncated at the
5 N-terminus.

B. Expression of human IKK α or of an antisense IKK α nucleic acid in a cell:

The full length IKK α cDNA and a cDNA encoding the Δ 31 human CHUK protein (Connelly and Marcu, *supra*,
10 1995) were subcloned into the Nde I and Xho I sites of a bacterial expression vector encoding a carboxy terminal FLAG epitope and HIS6 tag. Mammalian cell expression vectors were constructed by cleaving the bacterial
expression vector with Nde I and Hind III, to release the
15 cDNA inserts, converting the ends of the inserts to blunt ends using Klenow polymerase, and ligating the cDNA
inserts encoding the full length IKK α or the Δ 31 human CHUK into pCDNA3 (Invitrogen).

Alternatively, the IKK α cDNA and Δ 31 cDNA were
20 subcloned into the Bst XI site of the pRc β actin vector (DiDonato et al., *supra*, 1996). Orientation of the inserts (sense or antisense) was determined by restriction endonuclease mapping and partial sequence
using vector-specific primers. Vector containing the
25 cDNA's inserted in the sense orientation were examined for expression of the encoded product by immunoblot analysis using an antibody specific for the FLAG epitope.

Transfection experiments were performed to determine the effect of expressing the cloned IKK α in
30 HeLa cells or of expressing the cloned IKK α cDNA in the antisense orientation. One day prior to performing the transfections, HeLa cells were split into 35 mm dishes to approximately 50% confluency. Cells were transfected

with 0.25 μ g of a luciferase reporter gene containing an IL-8 promotor (Eckman et al., Amer. Soc. Clin. Invest. 96:1269-1279 (1995), which is incorporated herein by reference) along with either 1 μ g pCDNA3 (Invitrogen, La Jolla CA; vector control), 1 μ g pRc β actin-IKK α -AA (sense orientation), 1 μ g pRc β actin-IKK α -K (antisense), or 0.1 μ g pCDNA-IKK α -K using the LIPOFECTAMINE method as recommended by the manufacturer (GIBCO/BRL, Gaithersburg MD). Total DNA concentrations were kept constant by
10 addition of empty pRc β actin DNA.

Transfected cells were incubated in DMEM containing 10% FBS for 24 hr. The cells then were washed and the growth medium was replaced with DMEM containing 0.1% FBS. Cells either were left untreated, or were
15 treated with 20 ng/ml TNF α , 20 ng/ml IL-1 α , or 100 ng/ml TPA (phorbol ester) for 3.5 hr. Cells were harvested by scraping and washed once with PBS, then lysed in 100 μ l PBS containing 1% TRITON-X100. Luciferase assays were performed using 20 μ l of lysate (DiDonato et al., *supra*,
20 1995). The protein concentration of each extract was determined using the BIORAD protein assay kit and luciferase activity was normalized according to the protein concentrations.

NF- κ B is known to induce expression for the
25 IL-8 promotor. Thus, as expected, treatment of the vector transfected control cells with TNF α , IL-1 α or TPA resulted in a 3- to 5-fold increase in normalized luciferase activity. In comparison, in cells transfected with the cDNA encoding IKK α , treatment with TNF α , IL-1 α
30 or TPA potentiated induction of luciferase activity 5- to 6-fold above the level of induction observed in the vector transfected cells. These results indicate that expression of IKK α in cells increased the amount of NF- κ B activated in response to the inducing agents.

In cells transfected with the vector expressing the antisense IKK α nucleic acid molecule, transcription of the luciferase reporter gene induced by IL-1 or TNF α was at the limit of detection, indicating transcription was almost completely inhibited due to expression of the antisense IKK α . This result indicates that the native IKK α is turned over relatively rapidly in the cells. Furthermore, treatment of the cells with the various inducing agents had no effect on the level of luciferase expression of control reporter genes, which are not responsive to NF- κ B, as compared to the untreated cells. Other appropriate control experiments were performed in parallel. These results demonstrate that an expression of an antisense IKK α nucleic acid molecule in a cell can specifically inhibit NF- κ B mediated gene expression.

EXAMPLE III

IDENTIFICATION AND CHARACTERIZATION OF A FULL LENGTH HUMAN IKK β SUBUNIT

This example provides methods for isolating a nucleic acid molecule encoding an IKK β catalytic subunit of IKK and characterizing the activity of the IKK β subunit.

A. Cloning of IKK β cDNA:

IKK β was purified following SDS-PAGE and subjected to internal peptide sequencing (Example I). Five peptide sequences were obtained as follows: KIIDLGYAK (SEQ ID NO: 9); KXVHILN(M/Y) (V/G) (T/N/R/E) (G/N)TI (H/I/S) (SEQ ID NO: 10); KXXIQQD(T/A)GIP (SEQ ID NO: 11); KXRVIYTQL (SEQ ID NO: 12); and KXEEVVSLMNEDEK (SEQ ID NO: 13), where amino acid residues that could not be unambiguously determined are indicated by an "X" and where amino acids that could not be distinguished are shown in parentheses. These

peptide sequences were used to screen the NCBI EST database and a 336 base pair EST (EST29518; Accession No. AA326115) encoding SEQ ID NOS: 12 and 13 was identified. This EST was determined to correspond to amino acid
5 residues 551 to 661 of SEQ ID NO: 15.

cdNA corresponding to the EST was obtained by PCR using first strand HeLa cDNA as a template and used to probe a human fetal brain library (Clontech). A 1 kb fragment was identified and used as a probe to screen a
10 plasmid based B cell library (Invitrogen). A 3 kb cDNA insert was isolated and sequenced (Figure 2; SEQ ID NO: 14) and encoded the full length IKK β (SEQ ID NO: 15), including all five proteolytic fragments (see Figure 3).

Comparison of the amino acid sequences of IKK α
15 and IKK β revealed greater than 50% amino acid identity (Figure 3). In addition, SEQ ID NO: 15 contains a kinase domain, which shares 65% amino acid identity with IKK α , a leucine zipper and a helix-loop-helix domain. Based on the sequence homology and domain structure, the
20 polypeptide (SEQ ID NO: 15) was determined to be a member of the IKK catalytic subunit family of proteins with IKK α and, therefore, was designated IKK β .

B. Characterization of IKK β :

This section describes the results of various
25 assays characterizing IKK β activity, particularly with regard to its association with IKK α . In addition, northern blot analysis revealed that IKK β and IKK α are coexpressed in most tissues examined, including pancreas, kidney, skeletal muscle, lung, placenta, brain, heart,
30 peripheral blood lymphocytes, colon, small intestine, prostate, thymus and spleen.

1. IKK β kinase activity

The kinase activity associated with IKK β was characterized using HeLa or 293 cells transiently transfected with an HA-tagged IKK β expression vector. Transfected cells were stimulated with 20 ng/ml TNF for 10 min and HA-IKK β was isolated by immunoprecipitation using anti-HA antibody (Kolodziej and Young, Meth. Enzymol. 194:508-519 (1991)). The immune complexes were tested for the ability to phosphorylate wild type (wt) and mutant forms of I κ B α and I κ B β (see Example I).

Similarly to the purified IKK complex and the complex associated with IKK α , the IKK β immune complex phosphorylated wt I κ B α and I κ B β , but not mutants in which the inducible phosphorylation sites (Ser-32 and Ser-36 for I κ B α and Ser-19 and Ser-23 for I κ B α) were replaced with either alanines or threonines. However, a low level of residual phosphorylation of full length I κ B α (A32/A36) was observed due to phosphorylation of sites in the C-terminal portion of the protein (DiDonato et al., *supra*, 1997). Single substitution mutants, I κ B α (A32) and I κ B(A36), were phosphorylated almost as efficiently as wt I κ B α , indicating that IKK β -associated IKK activity can phosphorylate I κ B α at both Ser-32 and Ser-36.

The response of IKK β -associated kinase activity to various stimuli also was examined in HeLa cells transiently transfected with the HA-IKK β expression vector. After 24 hr, the cells were stimulated with either 10 ng/ml IL-1, 20 ng/ml TNF or 100 ng/ml TPA, then HA-IKK β immune complexes were isolated by immunoprecipitation and IKK activity was measured. TNF and IL-1 potently stimulated IKK β -associated kinase activity, whereas the response to TPA was weaker. The kinetics of IKK β activation by either TNF or IL-1 essentially were identical to the kinetics of activation

of the IKK α -associated I κ B kinase measured by a similar protocol.

2. Functional interactions between IKK α and IKK β

As shown in Example I, IKK α and IKK β copurified
5 in about a 1:1 ratio through several chromatographic
steps, suggesting that the two proteins interact with
each other. The ability of the IKK subunits to interact
in a functional complex and the effect of each subunit on
the activity of the other subunit was examined using
10 293 cells transfected with expression vectors encoding
Flag(M2)-IKK α or M2-IKK α and HA-IKK β , either alone or in
combination (see Hopp et al., BioTechnology 6:1204-1210
(1988)). After 24 hr, samples of the cells were
stimulated with TNF, lysates were prepared from
15 stimulated and unstimulated cells, and one portion of the
lysates was precipitated with anti-Flag antibodies
(Eastman Kodak Co.; New Haven CT) and another portion was
precipitated with anti-HA antibodies. The IKK activity
associated with the different immune complexes and their
20 content of IKK α and IKK β were measured.

Considerably more basal IKK activity was
precipitated with HA-IKK β than with Flag-IKK α . However,
the activity associated with HA-IKK β was further elevated
upon coexpression of M2-IKK α and the low basal activity
25 associated with Flag-IKK α was strongly augmented by
coexpression of IKK β . Immunoblot analysis revealed that
the potentiating effect of such coexpression was not due
to changes in the level of expression of IKK α or IKK β .

The levels of IKK activities associated with
30 IKK α and IKK β were compared more precisely by
transfecting 293 cells with increasing amounts of HA-IKK α
or HA-IKK β expression vectors (0.1 to 0.5 μ g/10⁶ cells)
and determining the kinase activities associated with the

two proteins in cell lysates prepared before or after TNF stimulation (20 ng/ml, 5 min); GST-IkB α (1-54) was used as substrate. The level of expression of each protein was determined by immunoblot analysis and used to calculate
5 the relative levels of specific IKK activity.

The HA-IKK α -associated IKK had a low level of basal specific activity, whereas expression of HA-IKK β resulted in high basal specific activity that was increased when higher amounts of HA-IKK β were expressed.
10 However, the specific IKK activity associated with either IKK α or IKK β isolated from TNF-stimulated cells was very similar and was not considerably affected by their expression level. These results indicate that titration of a negative regulator or formation of a constitutively
15 active IKK complex can occur due to overexpression of IKK β .

The ability of IKK α and IKK β to physically interact was examined. Immunoblot analysis demonstrated that precipitation of HA-IKK β using an anti-HA antibody
20 coprecipitated both endogenous IKK α and coexpressed Flag-IKK α , as indicated by the higher amount of coprecipitating IKK α detected after cotransfection with Flag-IKK α . Similarly, immunoprecipitation of Flag-IKK α with anti-Flag(M2) antibody resulted in coprecipitation
25 of cotransfected HA-IKK β . Exposure of the cells to TNF had no significant effect on the association of IKK α and IKK β .

The interaction between IKK α and IKK β was further examined by transfecting HeLa cells with various
30 amounts (0.1 to 1.0 μ g/ 10^6 cells) of the HA-IKK β vector. After 24 hr, the cells were incubated for 5 min in the absence or presence of 20 ng/ml TNF, then lysed. The lysates were examined for IKK activity and for the amount of HA-IKK β and endogenous IKK α . Expression of increasing

amounts of HA-IKK β resulted in higher basal levels of IKK activity and increasing amounts of coprecipitated IKK α . The level of TNF stimulated IKK activity increased only marginally in response to IKK β overexpression and TNF had
5 no effect on the association of IKK β and IKK α .

Since the results described above revealed that HA-IKK β associates with endogenous IKK α to generate a functional cytokine-regulated IKK complex, this association was examined further by transfecting HeLa
10 cells with either empty expression vector or small amounts (1 μ g/60 mm plate) of either HA-IKK α or HA-IKK β vectors. After 24 hr, samples of the transfected cell populations were stimulated with 20 ng/ml TNF for 5 min, then cell lysates were prepared and separated by gel
15 filtration on a SUPEROSE 6 column. One portion of each column fraction was immunoprecipitated with a polyclonal antibody specific for IKK α and assayed for IKK α -associated IKK activity, while a second portion was precipitated with anti-HA antibody and examined for
20 HA-IKK β - or HA-IKK α -associated IKK activity. Relative specific activity was determined by immunoprecipitating the complexes, separating the proteins by SDS-PAGE, blotting the proteins onto IMOBILON membranes (Millipore; Bedford MA), immunoblotting with anti-HA antibody and
25 quantitating the levels of I κ B phosphorylation and HA-tagged proteins by phosphoimaging. The results demonstrated that endogenous IKK α -associated IKK activity exists as two complexes, a larger complex of approximately 900 kDa and a smaller one of approximately
30 300 kDa. Stimulation with TNF increased the IKK activity of both complexes, although the extent of increase was considerably greater for the 900 kDa complex.

HA-IKK β -associated IKK activity had exactly the same distribution as the IKK α -associated activity,
35 eluting at 900 kDa and 300 kDa and, again, the extent of

TNF responsiveness was considerably greater for the 900 kDa complex. Comparison to the IKK α -associated activity in cells transfected with the empty vector indicated that HA-IKK β expression produced a modest, approximately 2-fold increase in the relative amount of IKK activity associated with the smaller 300 kDa complex. These results indicate that the 300 kDa IKK complex, like the 900 kDa complex, contains both IKK α and IKK β . However, the 300 kDa lacks other subunits present in the 900 kDa complex. When IKK β was overexpressed, the relative amount of the smaller complex increased, indicating that some of the subunits that are unique to the larger complex are present in a limited amount.

3. Both IKK α and IKK β contribute to IKK activity

The relative contribution of IKK α and IKK β to IKK activity was examined by constructing mutant subunits in which the lysine (K) codon present at position 44 of each subunit was substituted with a codon for either methionine (M) or alanine (A) codon, respectively. Similar mutations in other protein kinases render the enzymes defective in binding ATP and, therefore, catalytically inactive (Taylor et al., Ann. Rev. Cell Biol. 8:429-462 (1992)). The activity of the IKK mutants was compared to the activity of their wild type (wt) counterparts by cell-free translation in reticulocyte lysates using GST-IkB α (1-54) as a substrate. Translation of IKK α (KM) resulted in formation of IkB kinase having only slightly less activity than the IKK formed by translation of wt IKK α . In comparison, translation of IKK β (KA) did not generate IKK activity. Translation of wt IKK β generated IkB kinase activity as expected.

The activities of the different proteins also was examined by transient transfection in mammalian cells. Expression and immunoprecipitation of HA-IKK α (KM)

resulted in isolation of cytokine stimulated IKK activity that, after TNF stimulation, was 2-to 3-fold lower than the activity of IKK formed by wt HA-IKK α isolated from TNF-stimulated cells. Similarly, expression and
5 immunoprecipitation of HA-IKK β resulted in formation of a cytokine responsive IKK activity that, after TNF stimulation, was 3- to 5-fold lower than the activity of IKK generated by wt HA-IKK β isolated from TNF stimulated cells. In contrast to results obtained by overexpression
10 of wt HA-IKK β , however, overexpression of HA-IKK β (KA) did not result in the generation of basal IKK activity. Immunoprecipitation experiments revealed that IKK α (KM) associates IKK β and that IKK β (KA) associates with IKK α and that both IKK α and IKK β undergo homotypic
15 interactions as efficiently as they undergo heterotypic interactions.

Autophosphorylation of wt and kinase-defective HA-IKK α and HA-IKK β was examined in transiently transfected HeLa cells. HeLa cells expressing these
20 proteins were treated with TNF for 10 min, then cell lysates of TNF treated or untreated cells were immunoprecipitated with HA antibodies and the immune complexes were subjected to a phosphorylation reaction (DiDonato et al., *supra*, 1997). Both wt HA-IKK α and
25 wt HA-IKK β were phosphorylated and their autophosphorylation was enhanced in TNF-stimulated extracts. In contrast, the kinase-defective IKK α or IKK β mutants did not exhibit significant autophosphorylation.

4. The role of the LZ and HLH motifs in IKK α and IKK β

30 IKK α and IKK β both contain leucine zipper (LZ) and helix-loop-helix (HLH) motifs, which are known to mediate protein-protein interactions through their hydrophobic surfaces. The role of the LZ motif in the IKK subunit interaction was examined using an IKK α

mutant in which the L462 and L469 residues within the LZ region were substituted with serine residues. The role of the HLH motif was examined using an HLH mutant of IKK α containing a substitution of L605 with arginine (R) and
5 of F606 with proline (P). The activity of the IKK α LZ⁻ and HLH⁻ mutants was examined by transient transfection in 293 cells, either alone or in the presence of cotransfected Flag-IKK α .

Expression of wt HA-IKK α generated substantial
10 IKK activity that was isolated by immunoprecipitation with anti-HA, whereas very little IKK activity was generated in cells transfected with either the HA-IKK α (LZ)⁻ or HA-IKK α (HLH)⁻ mutant. Coexpression of the mutant IKK subunits with Flag-IKK β resulted in a
15 substantial increase in the IKK activity isolated by immunoprecipitation of HA-IKK α , but had no effect on the very low activity that coprecipitated with HA-IKK α (LZ)⁻. However, coexpression of Flag-IKK β did stimulate the low level of IKK activity associated with HA-IKK α (HLH)⁻.
20 Probing of the HA immune complexes with anti-Flag(M2) antibodies indicated that both wt HA-IKK α and HA-IKK α (HLH)⁻ associated with similar amounts of Flag-IKK β , but that the HA-IKK α (LZ)⁻ mutant did not associate with Flag-IKK β . These results indicate that
25 the lower I κ B kinase activity associated with the IKK α (LZ)⁻ mutant is due to a defect in its ability to interact with IKK β . The lower I κ B kinase activity of the IKK α (HLH)⁻ mutant, on the other hand, likely is due to a defect in the ability to interact with a second,
30 undefined protein, since the HLH mutant can interact with IKK β .

5. Both IKK α and IKK β are necessary for NF- κ B activation

The contribution of IKK α and IKK β to NF- κ B activation was examined using HeLa cells transfected with

expression vectors encoding HA-tagged wt IKK α , IKK α (KM),
wt IKK β and IKK β (KA); an HA-JNK1 vector was used as a
control. NF- κ B activation was assessed by examining the
subcellular distribution of RelA(p65) by indirect
5 immunofluorescence.

HeLa cells were grown on glass cover slips in
growth medium, then transfected with 1 μ g plasmid DNA by
the lipofectamine method. After 24 hr, samples of cells
were stimulated with 20 ng/ml TNF for 30 min, then
10 stimulated or unstimulated cells were washed with PBS and
fixed with 3.5% formaldehyde in PBS for 15 min at room
temperature (RT). The fixed cells were permeablized with
0.02% NP-40 in PBS for 1 min, then incubated with 100%
goat serum at 4°C for 12 hr. The cells then were washed
15 3 times with PBS and incubated with a mixture of a rabbit
anti-NF- κ B p65 (RelA) antibody (1:100 dilution; Santa
Cruz Biotech) and a mouse monoclonal anti-HA antibody in
PBS containing 1% BSA and 0.2% TRITON X-100 at 37 °C for
2 hr. Cells then were washed 3 times with PBS containing
20 0.2% TRITON X-100 and incubated for 2 hr at RT with
secondary antibodies, fluorescein-conjugated goat
affinity purified anti-mouse IgG-IgM and rhodamine-
conjugated IgG fraction goat anti-rabbit IgG (1:200
dilution; Cappel). Cells were washed 4 times with PBS
25 containing 0.2% TRITON X-100, then covered with a drop of
gelvatol mounting solution and viewed and photographed
using a Zeiss Axioplan microscope equipped for
epifluorescence with the aid of fluoroscein and rhodamine
specific filters.

30 Double staining with both anti-RelA and anti-HA
revealed that expression of moderate amounts of either
wt IKK α or wt IKK β did not produce considerable
stimulation of RelA nuclear translocation. In addition,
the wt IKK proteins did not interfere with the nuclear
35 translocation of RelA induced by TNF treatment. However,

expression of similar levels of either IKK α (KM) or IKK β (KA), as determined by the intensity of the fluorescent signal, inhibited the nuclear translocation of RelA in TNF-treated cells. Expression of HA-JNK1 had
5 no effect on the subcellular distribution of RelA. Since the subcellular distribution of RelA is dependent on the state and abundance of I κ B, these results indicate that expression of either IKK α (KM) or IKK β (KA) inhibits the induction of I κ B phosphorylation and degradation by TNF.

10

EXAMPLE IVISOLATION OF I κ B KINASE COMPLEX

This example demonstrates a method for isolating the 900 kDa I κ B kinase complex comprising an IKK α polypeptide.

15

Proteins that associate with IKK α *in vivo* were isolated by immunoprecipitation using HIS6 and FLAG epitope tags. The HIS6-FLAG-IKK α (HF-IKK α) encoding construct was prepared using a double stranded oligonucleotide, 5'-AGCTTGCGCGTATGGCTTCGGGTCATCACCATCACCA
20 TCACGGTGACTACAAGGACGACGATGACAAAGGTGACATCGAAGGTAGAGGTCA-3' (SEQ ID NO: 16), which encodes six histidine residues (HIS6), the FLAG epitope and the factor Xa site in tandem. The oligonucleotide was inserted using HindIII-NdeI site in frame with the N-terminus of the IKK α coding
25 sequence in the BLUESCRIPT KS plasmid (Stratagene; La Jolla CA). The HindIII-NotI fragment of this plasmid, which contains the HF-IKK α cDNA sequence, was subcloned into the pRc β actin mammalian expression vector, which contains a nucleic acid sequence conferring neomycin
30 resistance, to produce plasmid pRC-HF-IKK α . Expression of the HF-IKK α polypeptide was confirmed by western blot analysis using anti-FLAG antibodies.

pRC-HF-IKK α was transfected into human embryonic kidney 293 cells and transfected cells were selected for growth in the presence of G418. A low basal level of IKK activity was detected in cells expressing HF-IKK α and IKK activity increased several fold when the cells were treated with TNF α . This result indicates that the HF-IKK α expression in 293 cells is associated with IKK activity in the cells and that such IKK activity is inducible in response to TNF α .

A 293 cell line that expresses HF-IKK α was selected and expanded to approximately 4×10^8 cells. The cells were treated with 10 ng/ml TNF α for 5 min, then harvested in ice cold PBS by centrifugation at 2500 x g. The cell pellet was washed with ice cold PBS, resuspended in lysis buffer (20 mM Tris, pH 7.6), 150 mM NaCl, 1% TRITON X-100, 20 mM β -glycerophosphate, 2 mM PNPP, 1 mM Na₃VO₄, 5 mM β -mercaptoethanol, 1 mM EDTA, 0.5 mM EGTA, 1 mM PMSF, 3 μ g/ml pepstatin, 3 μ g/ml leupeptin, 10 μ g/ml bestatin and 25 μ g/ml aprotinin), and lysed by 20 strokes in a glass Dounce homogenizer (pestle A).

The homogenate was centrifuged at 15,000 rpm in a Beckman SS34 rotor for 30 min at 4°C. The supernatant was collected, supplemented with 20 mM imidazole and 300 mM NaCl, then mixed with 0.5 ml of a 50% slurry of Ni-NTA (nickel nitrilotriacetic acid; Qiagen, Inc.; Chatsworth CA) and stirred for 4 hr at 4°C. Following incubation, the resin was pelleted at 200 x g and the supernatant was removed. The resin was washed 3 times with 50 ml binding buffer containing 25 mM imidazole.

Proteins bound to the resin were eluted in 2 ml binding buffer containing 150 mM imidazole and 20 mM DTT. The eluate was mixed with 100 μ l of a 50% slurry of anti-FLAG antibody coupled to SEPHAROSE resin using the AMINOLINK PLUS immobilization kit (Pierce Chem. Co.;

Rockford IL) and stirred for 4 hr at 4°C. The resin was pelleted at 1000 x g, the supernatant was removed, and the resin was washed with 10 ml binding buffer (without imidazole). Proteins bound to the resin then were eluted
5 with 1% SDS or with FLAG peptide and examined by 10% SDS-PAGE.

Silver staining revealed the presence of seven proteins, including the HF-IKK α , which was confirmed by western blot analysis using anti-FLAG antibody. The
10 copurified proteins had apparent molecular masses of about 100 kDa, 63 kDa, 60 kDa, 55 kDa, 46 kDa and 29 kDa; the endogenous 87 kDa IKK β comigrates with the HA-IKK α protein. These results indicate that IKK α , along with some or all of the copurifying proteins, comprise the
15 900 kDa I κ B kinase complex.

EXAMPLE V

ANTI-IKK ANTISERA

This example provides a method of producing anti-IKK antisera.

20 Anti-IKK α antibodies were raised in rabbits using either His-tagged IKK α expressed in *E. coli* or the IKK α peptide ERPPGLRPGAGGPWE (SEQ ID NO: 17) or TIIHEAWEEQGNS (SEQ ID NO: 18) as an immunogen. Anti-IKK β antibodies were raised using the peptide SKVRGPVSGSPDS
25 (SEQ ID NO: 19). The peptides were conjugated to keyhole limpet hemocyanin (Sigma Chemical Co.; St. Louis MO). Rabbits were immunized with 250 to 500 μ g conjugated peptide in complete Freund's adjuvant. Three weeks after the primary immunization, booster immunizations were
30 performed using 50 to 100 μ g immunogen and were repeated three times, at 3 to 4 week intervals. Rabbits were bled one week after the final booster and antisera were

collected. Anti-IKK α antiserum was specific for IKK α and did not cross react with IKK β .

EXAMPLE VI

USE OF AN IKK SUBUNIT IN A DRUG SCREENING ASSAY

5 This example describes an assay for screening for agents such as drugs that alter the association of an IKK subunit and a second protein that specifically associates with the IKK subunit.

 A GST-IKK subunit fusion protein or HIS6-IKK
10 subunit fusion protein can be prepared using methods as described above and purified using glutathione- or metal-chelation chromatography, respectively (Smith and Johnson, Gene 67:31-40 (1988), which is incorporated herein by reference; see, also, Example IV). The fusion
15 protein is immobilized to a solid support taking advantage of the ability of the GST protein to specifically bind glutathione or of the HIS6 peptide region to chelate a metal ion such as nickel (Ni) ion or cobalt (Co) ion (Clontech) by immobilized metal affinity
20 chromatography. Alternatively, an anti-IKK antibody can be immobilized on a matrix and the IKK- α can be allowed to bind to the antibody.

 The second protein, which can be I κ B or a protein that copurifies with IKK subunit as part of the
25 900 kDa I κ B kinase, for example, can be detectably labeled with a moiety such as a fluorescent molecule or a radiolabel (Hermanson, *supra*, 1996), then contacted in solution with the immobilized IKK subunit under conditions as described in Example I, which allow I κ B to
30 specifically associate with the IKK subunit. Preferably, the reactions are performed in 96 well plates, which allow automated reading of the reactions. Various agents

such as drugs then are screened for the ability to alter the association of the IKK subunit and IκB.

The agent and labeled IκB, for example, can be added together to the immobilized IKK subunit, incubated
5 to allow binding, then washed to remove unbound labeled IκB. The relative amount of binding of labeled IκB in the absence as compared to the presence of the agent being screened is determined by detecting the amount of label remaining in the plate. Appropriate controls are
10 performed to account, for example, for nonspecific binding of the labeled IκB to the matrix. Such a method allows the identification of an agent that alter the association of an IKK subunit and a second protein such as IκB.

15 Alternatively, the labeled IκB or other appropriate second protein can be added to the immobilized IKK subunit and allowed to associate, then the agent can be added. Such a method allows the identification of agents that can induce the dissociation
20 of a bound complex comprising the IKK subunit and IκB. Similarly, a screening assay of the invention can be performed using the 900 kDa IKK complex, comprising an IKK subunit.

25 Although the invention has been described with reference to the examples provided above, it should be understood that various modifications can be made without departing from the spirit of the invention. Accordingly, the invention is limited only by the claims.

We claim:

1. An isolated nucleic acid molecule,
comprising a nucleotide sequence encoding an I κ B kinase
(IKK) subunit, IKK β , which phosphorylates the inhibitor
5 of NF- κ B (I κ B α) on serine-32 and serine-36 and has an
apparent molecular mass of about 87 kiloDaltons; or a
nucleotide sequence complementary thereto.

2. The nucleic acid molecule of claim 1,
comprising the nucleotide sequence shown in SEQ ID
10 NO: 14.

3. The nucleic acid molecule of claim 1,
comprising a nucleotide sequence encoding the amino acid
sequence shown in SEQ ID NO: 15.

4. A polynucleotide, comprising a nucleotide
15 sequence selected from the group consisting of:

a) a nucleotide sequence encoding at least
three contiguous amino acids of SEQ ID NO: 15;

b) a nucleotide sequence complementary to
a nucleotide sequence encoding at least three
20 contiguous amino acids of SEQ ID NO: 15; and

c) a mixture of nucleotide sequence,
comprising a nucleotide sequence encoding at
least three contiguous amino acids of SEQ ID
NO: 15, and a nucleotide sequence complementary
25 thereto, wherein said mixture comprises single
stranded polynucleotides or double stranded
polynucleotides.

5. An antisense nucleic acid molecule,
comprising a polynucleotide sequence complementary to at
least nine contiguous nucleotides of SEQ ID NO: 14 or
complementary to a nucleotide sequence encoding at least
5 three contiguous amino acids of SEQ ID NO: 15.

6. An isolated nucleic acid molecule,
comprising a nucleotide sequence encoding a full length
human I κ B kinase, which phosphorylates the inhibitor of
NF- κ B (I κ B α) on serine-32 and serine-36 and has an
10 apparent molecular mass of about 85 kiloDaltons; or a
nucleotide sequence complementary thereto.

7. The nucleic acid molecule of claim 6,
comprising the nucleotide sequence shown in SEQ ID NO: 1.

8. The nucleic acid molecule of claim 6,
15 comprising a nucleotide sequence encoding the amino acid
sequence shown in SEQ ID NO: 2.

9. A polynucleotide, comprising a nucleotide
sequence selected from the group consisting of:

20 a) at least nine contiguous nucleotides
of SEQ ID NO: 1, said at least nine contiguous
nucleotides further comprising at least three
contiguous nucleotides of the nucleotide
sequence shown as positions -35 to 92 of SEQ ID
NO: 1;

25 b) a nucleotide sequence complementary to
said at least nine contiguous nucleotides of
SEQ ID NO: 1; and

c) a mixture of said at least nine contiguous nucleotide and said nucleotide sequence complementary thereto, wherein said mixture comprises single stranded
5 polynucleotides or double stranded polynucleotides.

10. An antisense nucleic acid molecule, comprising a polynucleotide sequence complementary to at least nine contiguous nucleotides of SEQ ID NO: 1,
10 further comprising at least three contiguous nucleotides within positions -35 to 92 of SEQ ID NO: 1, wherein said polynucleotide sequence binds to and inhibits the expression of a nucleic acid molecule encoding an I κ B kinase.

15 11. A vector, comprising the nucleic acid molecule or the polynucleotide of any of claims 1 to 10.

12. The vector of claim 11, which is an expression vector.

20 13. The vector of claim 11, which is a viral vector.

14. A host cell containing the vector of claim 11.

25 15. An isolated I κ B kinase β subunit (IKK β), wherein said IKK β phosphorylates serine-32 and serine-36 of I κ B α and has an apparent molecular mass of 87 kiloDaltons as determined by SDS-polyacrylamide gel electrophoresis in an 8% gel under reducing conditions.

16. The isolated IKK β of claim 15, comprising the amino acid sequence as shown in SEQ ID NO: 15.

17. A peptide, comprising at least three contiguous amino acids of SEQ ID NO: 15.

18. An isolated human I κ B kinase α subunit (IKK α), wherein said IKK α phosphorylates serine-32 and
5 serine-36 of I κ B α and which has an apparent molecular mass of about 85 kiloDaltons as determined by SDS-polyacrylamide gel electrophoresis in an 8% gel under reducing conditions.

19. The isolated human IKK α of claim 18,
10 comprising the amino acid sequence of SEQ ID NO: 2.

20. A peptide portion of the human IKK α of claim 19, comprising at least two contiguous amino acids within positions 1 to 31 of SEQ ID NO: 2.

21. The peptide of claim 20, wherein one of
15 said at least two contiguous amino acids further comprises the amino acid shown at position 30 or position 31 of SEQ ID NO: 2.

22. An antibody that specifically binds to an epitope comprising an amino acid of SEQ ID NO: 15,
20 provided said epitope is not present in SEQ ID NO: 2.

23. An antibody that specifically binds to an epitope comprising an amino acid present within positions 1 to 31 of SEQ ID NO: 2.

24. The antibody of claim 23, wherein said
25 amino acid is the amino acid shown at position 30 of SEQ ID NO: 2.

25. A cell line producing the antibody of any of claims 22 to 24.

26. The cell line of claim 25, which is a hybridoma cell line.

27. A method of identifying an agent that modulates the specific association of an I κ B kinase (IKK) subunit and a second protein, comprising the steps of:

10 a) contacting the IKK subunit and the second protein, under conditions suitable for the specific association of said IKK subunit and said second protein, with an agent suspected of being able to modulate said specific association; and

15 b) detecting an altered association of said IKK subunit and said second protein in the presence of said agent, wherein said altered association identifies an agent that modulates the specific association of said IKK subunit and said second protein.

28. The method of claim 27, wherein said contacting is in an *in vitro* reaction and said IKK subunit is isolated.

29. The method of claim 27, wherein said contacting is in a cell in culture.

30. The method of claim 29, wherein said cell is selected from the group consisting of a mammalian cell and a yeast cell.

31. The method of claim 27, wherein said altered association is detected by measuring the transcriptional activity of a reporter gene.

32. The method of claim 27, wherein said IKK subunit is IKK α or IKK β .

33. The method of claim 27, wherein said second protein is an I κ B protein.

5 34. The method of claim 33, wherein said I κ B protein is selected from the group consisting of I κ B α and I κ B β .

 35. The method of claim 27, wherein said second protein is a subunit of a 300 kDa IKK complex or a
10 900 kDa IKK complex.

 36. The method of claim 35, wherein said second protein subunit is IKK α or IKK β .

 37. The method of claim 27, wherein said agent is an organic molecule.

15 38. The method of claim 27, wherein said agent is a peptide.

 39. The method of claim 38, wherein said peptide is a mutant I κ B protein selected from the group consisting of a mutant I κ B α containing amino acid
20 substitutions for serine-32 and for serine-36; and a mutant I κ B β containing amino acid substitutions for serine-19 and for serine-23.

40. A method for identifying an agent that alters I κ B kinase (IKK) activity, comprising the steps of:

5 a) incubating an isolated composition having IKK activity with an agent suspected of being able to alter said IKK activity; and

10 b) determining altered IKK activity of said composition in the presence of said agent, wherein said altered IKK activity identifies an agent that alters said IKK activity of said composition.

41. The method of claim 40, wherein said agent is a protein kinase inhibitor.

15 42. The method of claim 40, wherein said composition comprises an IKK subunit.

43. The method of claim 40, wherein said composition comprises a 300 kDa I κ B kinase complex or a 900 kDa I κ B kinase complex.

20 44. The method of claim 43, wherein said composition comprises IKK α or IKK β .

45. A method of obtaining isolated I κ B kinase (IKK) from a sample containing the IKK, comprising the steps of:

25 a) contacting the sample containing the IKK with an antibody that specifically binds an epitope of the IKK; and

b) obtaining isolated IKK bound to said antibody.

46. The method of claim 45, wherein said antibody specifically binds an IKK catalytic subunit.

47. The method of claim 45, wherein said catalytic subunit is IKK α or IKK β .

5

48. The method of claim 45, wherein said antibody specifically binds a tag linked to an IKK catalytic subunit.

49. The method of claim 48, wherein said tag
10 comprises a peptide tag selected from an HA tag, a HIS6 tag and a FLAG tag.

50. The method of claim 45, wherein said isolated IKK is an IKK complex.

51. The method of claim 50, wherein said IKK
15 complex is a 300 kDa IKK complex or a 900 kDa IKK complex.

52. A method of obtaining substantially purified I κ B kinase (IKK) from a sample containing the IKK, comprising the steps of:

20 a) contacting the sample containing the IKK with adenosine triphosphate (ATP) immobilized on a matrix, under conditions suitable for binding of said IKK with said ATP;

25 b) obtaining the fraction of said sample that binds to said ATP, said fraction containing said IKK;

c) contacting said fraction containing said I κ B kinase with I κ B immobilized on a

matrix, under conditions suitable for binding of said IκB kinase with said IκB; and

d) obtaining substantially purified IκB kinase from said IκB immobilized on a matrix.

5 53. A method of modulating NF-κB activity in a cell, comprising contacting the cell with an agent that alters the association of an IκB kinase (IKK) or an IKK catalytic subunit and a second protein.

10 54. A method of modulating NF-κB activity in a cell, comprising contacting the cell with an agent that alters the activity of an IκB kinase.

 55. A method of modulating NF-κB activity in a cell, comprising introducing into the cell an antisense IκB kinase (IKK) subunit nucleic acid molecule.

15 56. The method of claim 55, wherein said antisense IKK subunit nucleic acid molecule is expressed in the cell from a vector.

WO 98/37228

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TCGACGGAACCTGAGGCCGCTTGCCCTCCGCCCC

60

1
atggagcggcccccggggctgcggccgggcgcgggcgggccctgggagatgcgggagcgg
M E R P P G L R P G A G G P W E M R E R
61 120
ctgggcaccggcggccttcgggaacgtctgtctgtaccagcatcgggaacttgatctcaaa
L G T G G F G N V C L Y Q H R E L D L K
121 180
atagcaattaagtcttgcctagagctaagtaacaaaaacagagaacgatggtgccat
I A I K S C R L E L S T K N R E R W C H
181 240
gaaatccagattatgaagaagttgaaccatgccaatgttgtaaaggcctgtgatgttccct
E I Q I M K K L N H A N V V K A C D V P
241 300
gaagaattgaatatatttgattcatgatgtgcctcttctagcaatggaatactgttctgga
E E L N I L I H D V P L L A M E Y C S G
301 360
ggagatctccgaaagctgctcaacaaaccagaaaattgttggtggacttaaagaaagccag
G D L R K L L N K P E N C C G L K E S Q
361 420
atactttctttactaagtgatatagggctctgggattcgatatttgcatgaaaacaaaatt
I L S L L S D I G S G I R Y L H E N K I
421 480
atacatcgagatctaaaacctgaaaacatagttcttcaggatggttggtggaaagataata
I H R D L K P E N I V L O D V G G K I I
481 (peptide 1) 540
cataaaataattgatctgggatatgccaaagatgttgatcaaggaagtctgtgtacatct
H K I I D L G Y A K D V D Q G S L C T S
541 600
tttgtgggaacactgcagtatctggccccagagctctttgagaataagccttacacagcc
F V G T L Q Y L A P E L F E N K P Y T A
601 660
actgttgattattggagctttgggaccatggtatttgatgtattgctggatataggcct
T V D Y W S F G T M V F E C I A G Y R P
661 720
tttttgcatcatctgcagccatttacctggcatgagaagattaagaagaaggatccnaag
F L H H L Q P F T W H E K I K K K D P K
721 780
tgtatatttgcatgtgaagagatgtcaggagaagttcggttttagtagccatttacctcaa
C I F A C E E M S G E V R F S S H L P Q
781 840
ccaaatagcctttgtagtttaatagtagaaccatggaaaactggctacagttgatgttg
P N S L C S L I V E P M E N W L Q L M L
841 900
aattgggaccctcagcagagaggaggacctgttgaccttactttgaagcagccaagatgt
N W D P Q Q R G G P V D L T L K Q P R C
901 960
tttgtattaatggatcacattttgaatttgaagatagtagacacatcctaaatatgacttct
F V L M D H I L N L K I V H I L N M T S
961 1020

FIG. 1A
SUBSTITUTE SHEET (RULE 26)

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gcaaagataatttcttttctgttaccacctgatgaaagtcttcattcactacagtctcgt
 A K I I S F L L P P D E S L H S L Q S R
 1021 1080
 attgagcgtgaaactggaataaatactgggttctcaagaacttctttcagagacaggaatt
 I E R E T G I N T G S Q E L L S E T G I
 1081 1140
 tctctggatcctcggaaaccagcctctcaatgtgttctagatggagtttagaggctgtgat
 S L D P R K P A S Q C V L D G V R G C D
 1141 1200
 agctatatggttttatttggttgataaaagttaaactgtatatgaagggccatttgcttcc
 S Y M V Y L F D K S K T V Y E G P F A S
 1201 1260
 agaagtttatctgattgtgttaaattatattgtacaggacagcaaaatacagcttccaatt
 R S L S D C V N Y I V Q D S K I Q L P I
 1261 1320
 atacagctgcgtaaagtgtgggctgaagcagtgccactatgtgtctggactaaaagaagac
 I Q L R K V W A E A V H Y V S G L K E D
 1321 1380
 tatagcaggctctttcagggacaaagggcagcaatgttaagtcttcttagatataatgct
 Y S R L F Q G Q R A A M L S L L R Y N A
 1381 1440
 aacttaacaaaaatgaagaacactttgatctcagcatcacaacaactgaaagctaaattg
 N L T K M K N T L I S A S Q Q L K A K L
 1441 1500
 gagttttttcacaaaagcattcagcttgacttggagagatacagcgcagcagatgacgtat
 E F F H K S I Q L D L E R Y S E Q M T Y
 1501 1560
 gggatatcttcagaaaaaatgctaaaagcatggaaagaaatggaagaaaaggccatccac
 G I S S E K M L K A W K E M E E K A I H
 1561 1620
 tatgctgaggttggtgtcattggatacctggaggatcagattatgtctttgcatgctgaa
 Y A E V G V I G Y L E D Q I M S L H A E
 1621 1680
 atcatggggctacagaagagcccctatggaagacgtcagggagacttgatggaatctctg
 I M G L Q K S P Y G R R Q G D L M E S L
 1681 1740
 gaacagcgtgccattgatctatataagcagttaaaacacagaccttcagatcactcctac
 E Q R A I D L Y K Q L K H R P S D H S Y
 1741 1800
 agtgacagcacagagatgggtgaaaatcattgtgcacactgtgcagagtcaggaccgtgtg
 S D S T E M V K I I V H T V Q S Q D R V
 1801 1860
 ctcaaggagctgtttggtcatttgagcaagttgttgggctgtaagcagaagattattgat
 L K E L F G H L S K L L G C K Q K I I D
 1861 (peptide 2) 1920
 ctactccctaaggtggaagtggccctcagtaatatcaaagaagctgacaatactgtcatg
L L P K V E V A L S N I K E A D N T V M
 1921 1980
 ttcatgcagggaaaaaggcagaaagaaatatggcatctccttaaaattgcctgtacacag
 F M Q G K R Q K E I W H L L K I A C T Q
 1981 2040
 agttctgcccgtcccttgtaggatccagtctagaaggtgcagtaaccctcagacatca
 S S A R S L V G S S L E G A V T P Q T S

FIG. 1B

SUBSTITUTE SHEET (RULE 26)

3 / 6

2041 2100
gcatggctgccccgacttcagcagaaatgatcattctctgtcatgtgtggtaactcct
A W L P P T S A E H D H S L S C V V T P
2101 2160
caagatggggagacttcagcacaaatgataagaagaaaatttgaactgccttggccattta
Q D G E T S A Q M I E E N L N C L G H L
2161 2220
agcactattattcatgaggcaaatagaggaacagggcaatagtatgatgaatcttgattgg
S T I I H E A N E E Q G N S M M N L D W

agttggttaacagaatga
S W L T E *
2221 2238

FIG. 1C

WO 98/37228

PCT/US98/03511

4/6

1 CGCGTCCCTG CCGACAGAGT TAGCACGACA TCAGTATGAG CTGGTCACCT TCCCTGACAA
61 CGCAGACATG CGGGGCCTGG GAAATGAAAG AGCGCCTTGG GACAGGGGGA TTTGGAAATG
121 TCATCCGATG GCACAATCAG GAAACAGGTG AGCAGATTGC CATCAAGCAG TGCCGGCAGG
181 AGCTCAGCCC CCGGAACCGA GAGCGGTGGT GCCTGGAGAT CCAGATCATG AGAAGGCTGA
241 CCCACCCCAA TGTGGTGGCT GCCCGAGATG TCCCTGAGGG GATGCAGAAC TTGGCGCCCA
301 ATGACCTGCC CCTGCTGGCC ATGGAGTACT GCCAAGGAGG AGATCTCCGG AAGTACCTGA
361 ACCAGTTTGA GAACTGCTGT GGTCTGCGGG AAGGTGCCAT CCTCACCTTG CTGAGTGACA
421 TTGCCTCTGC GCTTAGATAC CTTTCATGAAA ACAGAATCAT CCATCGGGAT CTAAAGCCAG
481 AAAACATCGT CCTGCAGCAA GGAGAACAGA GGTTAATACA CAAAATTATT GACCTAGGAT
541 ATGCCAAGGA GCTGGATCAG GGCAGTCTTT GCACATCATT CGTGGGGACC CTGCAGTACC
601 TGGCCCCAGA GCTACTGGAG CAGCAGAAGT ACACAGTGAC CGTCGACTAC TGGAGCTTCG
661 GCACCCTGGC CTTTGAGTGC ATCACGGGCT TCCGGCCCTT CCTCCCCAAC TGGCAGCCCG
721 TGCAGTGGCA TTCAAAAGTG CGGCAGAAGA GTGAGGTGGA CATTGTTGTT AGCGAAGACT
781 TGAATGGAAC GGTGAAGTTT TCAAGCTCTT TACCCTACCC CAATAATCTT AACAGTGTCC
841 TGGCTGAGCG ACTGGAGAAG TGGCTGCAAC TGATGCTGAT GTGGCACCCC CGACAGAGGG
901 GCACGGATCC CACGTATGGG CCCAATGGCT GCTTCAAGGC CCTGGATGAC ATCTTAAACT
961 TAAAGCTGGT TCATATCTTG AACATGGTCA CGGGCACCAT CCACACCTAC CCTGTGACAG
1021 AGGATGAGAG TCTGCAGAGC TTGAAGGCCA GAATCCAACA GGACACGGGC ATCCCAGAGG
1081 AGGACCAGGA GCTGCTGCAG GAAGCGGGCC TGGCGTTGAT CCCCATAAG CCTGCCACTC
1141 AGTGTATTTT AGACGGCAAG TTAAATGAGG GCCACACATT GGACATGGAT CTTGTTTTTC
1201 TCTTTGACAA CAGTAAAATC ACCTATGAGA CTCAGATCTC CCCACGGCCC CAACCTGAAA
1261 GTGTCAGCTG TATCCTTCAA GAGCCCAAGA GGAATCTCGC CTTCTTCCAG CTGAGGAAGG
1321 TGTGGGGCCA GGTCTGGCAC AGCATCCAGA CCCTGAAGGA AGATTGCAAC CGGCTGCAGC
1381 AGGGACAGCG AGCCGCCATG ATGAATCTCC TCCGAAACAA CAGCTGCCTC TCCAAAATGA
1441 AGAATTCCAT GGCTTCCATG TCTCAGCAGC TCAAGGCCAA GTTGATTTT TTCAAAACCA
1501 GCATCCAGAT TGACCTGGAG AAGTACAGCG AGCAAACCGA GTTTGGGATC ACATCAGATA
1561 AACTGCTGCT GGCCTGGAGG GAAATGGAGC AGGCTGTGGA GCTCTGTGGG CGGGAGAACG
1621 AAGTGAAACT CCTGGTAGAA CGGATGATGG CTCTGCAGAC CGACATTGTG GACTTACAGA
1681 GGAGCCCCAT GGGCCGGAAG CAGGGGGGAA CGCTGGACGA CCTAGAGGAG CAAGCAAGGG

FIG. 2A
SUBSTITUTE SHEET (RULE 26)

5/6

1741 AGCTGTACAG GAGACTAAGG GAAAAACCTC GAGACCAGCG AACTGAGGGT GACAGTCAGG
1801 AAATGGTACG GCTGCTGCTT CAGGCAATTC AGAGCTTCGA GAAGAAAGTG CGAGTGATCT
1861 ATACGCAGCT CAGTAAACT GTGGTTTGCA AGCAGAAGGC GCTGGAACTG TTGCCCAAGG
1921 TGGAAGAGGT GGTGAGCTTA ATGAATGAGG ATGAGAAGAC TGTGTCCGG CTGCAGGAGA
1981 AGCGGCAGAA GGAGCTCTGG AATCTCCTGA AGATTGCTTG TAGCAAGGTC CGTGGTCCTG
2041 TCAGTGGAAG CCCGGATAGC ATGAATGCCT CTCGACTTAG CCAGCCTGGG CAGCTGATGT
2101 CTCAGCCCTC CACGGCCTCC AACAGCTTAC CTGAGCCAGC CAAGAAGAGT GAAGAACTGG
2161 TGGCTGAAGC ACATAACCTC TGCACCCTGC TAGAAAATGC CATAAGGAC ACTGTGAGGG
2221 AACAAGACCA GAGTTTCACG GCCCTAGACT GGAGCTGGTT ACAGACGGAA GAAGAAGAGC
2281 ACAGCTGCCT GGAGCAGGCC TCATGATGTG GGGGGACTCG ACCCCCTGAC ATGGGGCAGC
2341 CCATAGCAGG CCTTGTGCAG TGGGGGGACT CGACCCCTG ACATGGGGCT GCCTGGAGCA
2401 GGCCGCGTGA CGTGGGGCTG CCTGGCCGTG GCTCTCACAT GGTGGTTCCT GCTGCACTGA
2461 TGGCCCAGGG GTCTCTGGTA TCCAGATGGA GCTCTCGCTT CCTCAGCAGC TGTGACTTTC
2521 ACCCAGGACC CAGGACGCAG CCCTCCGTGG GCACTGCCGG CGCCTTGTCT GCACACTGGA
2581 GGTCTCCAT TACAGAGGCC CAGCGCACAT CGCTGGCCCC ACAAACGTTC AGGGGTACAG
2641 CCATGGCAGC TCCTTCCTCT GCCGTGAGAA AAGTGCTTGG AGTACGGTTT GCCACACACG
2701 TGA CTGGACA GTGTCCAATT CAAATCTTTC AGGGCAGAGT CCGAGCAGCG CTTGGTGACA
2761 GCCTGTCCTC TCCTGCTCTC CAAAGGCCCT GCTCCCTGTC CTCTCTCACT TTACAGCTTG
2821 TGTTTCTTCT GGATTCAGCT TCTCCTAAAC AGACAGTTTA ATTATAGTTG CGGCCTGGCC
2881 CCATCCTCAC TTCCTCTTTT TATTTCAGT CTGCTAAAAT TGTGTTTTTA C

FIG. 2B

WO 98/37228

PCT/US98/03511

6 / 6

α	MERPPGLRPGAGG ^W EMRERLGTGGFGNVCLYQHRELDLKIAIKSCRLELSTKNRERWCH	60
β	MSWSPSLTTQTTCGAWEMKERLGTGGFGNVIRWHNQETGEQIAIKQCRQELSPRNRERWCL	60
α	EIQIMKKLNHANVVKACDVPEEL.NILIHDPVLLAMEYCSGGDLRKLLNKPENCCGLKES	119
β	EIQIMRRLTHPNVVAARDVPEGMQN ^L LAPNDLPLAMEYCOGGDLRKYL ^N QFENCCGLREG	120
α	QILSLLSDIGSGIRYLHENKIIHRDLKPENIVLQDVGGKIIHKIIDLGYAKDVDQGS ^L CT	179
β	AILTLLSDIASALRYLHENRIIHRDLKPENIVLQOGEQRLIHKIIDLGYAKELDQGS ^L CT	180
α	SFVGT ^L QYLAPELFENKPYTATVDYWSFGTMVFECIAGYRPFLLHHLQ ^P FTWHEKIKKKDP	239
β	SFVGT ^L QYLAPELLEQQKYTVTVDYWSFGTLAFECITGFRPFLPNWQPVQ ^W HSKVRQKSE	240
α	KCIFACEEMSGEVRFSSHL ^P QPN ^S LC ^S LIVEPMENWLQ ^L MLNWD ^P QQRGGPVD ^L TLKQ ^P R	299
β	VDIVVSED ^L NGTVKFSSSLPYPNNLNSVLAERLEKWLQ ^L MLMWHPRQ ^R GT..DPTYGPNG	298
α	C ^F V ^L MDHILNLKIVHILNMTSAKIIISFLLPPDESLHSLQ ^S RIERETGINTGSQ ^E LLSETG	359
β	C ^F KALDDILNLKLYHILNMVTGTIHTYPVTEDES ^L QSLKAR ^I OODTGIPEEDQ ^E LLQEAG	358
α	ISLDPRKPASQCV....LDGVRGCDSYMVYLFDKSKTVYEGPFASRSLSDCVNYIVQ ^D SK	415
β	LALIPDKPATQCISDGKLN ^E GHTLDMDLVFLFDNSKIT ^Y ETQISPRPQ ^P ESVSCILQ ^E PK	418
α	IQLPIIQLRKVWAEAVHYVSGLKEDYSRLFQ ^G QRAAML ^S LLRYNANLTKMKNTLISASQ ^Q	475
β	RNLAFFQLRKVWGQVWHSIQTLKEDCNRLQ ^Q GQRAAMNLLRNNSCLSKMKNSMASMSQ ^Q	478
α	LKAKLEFFHKS ^I QDLERYSEQMTYGISSEKMLKAWKEMEEKAIHYAEVGVIGYLEDQ ^I M	535
β	LKAKLDFFKTSIQIDLEKYSEQTEFGITS ^D KLL ^L AWREMEQAVELCGRENEVKLLVERMM	538
α	SLHAEIMGLQKSPYGRRQGDLMESLEQRAIDLYKQLK ^H RPSDH.SYSDSTEMVKIIVHTV	594
β	ALQTDIVDLQ ^R SPMGRKQGGTLDDLEEQA ^R E ^L YRRLREKPRDQ ^R TEGDSQEMVRL ^L LQAI	598
α	QSD ^R V ^L KELFGHLSKLLGCKIQKIIDLLPKVEVALSNIKEADNT ^V MFMOGKROKEIWHLL	654
β	QSF ^E KKVRV ^I YTOLSKTVVCKQKALELLPKVEEVVSLMNEDEKT ^V VRLQEKROKELWNLL	658
α	KIACTQSSARSLVGSSLEGAVTPQTSAWLPPTSAEHDHSLSCVVTPQDGETSAQMIEENL	714
β	KIAC..SKVRGPVSGSPDSMNASRLS...QPGQLMSQPSTASNSLPEPAKKSEELVAEAH	713
α	NCLGHLSTIIHEANEEQGN ^S MMNLDWSWLTE.....	745
β	NLCTLLENAIQDTVREQDQSFTALDWSWLQTEEEHSCLEQAS	756

FIG. 3

SUBSTITUTE SHEET (RULE 26)